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Field Operations and Enforcement Manual for Air Pollution Control

Vol. 2 control technology and general source inspection

Pacific Environmental Services, Inc.

prepared for

Environmental Protection Agency

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FIELD OPERATIONS AND ENFORCEMENT MANUAL FOR AIR POLLUTION CONTROL

VOLUME II:

CONTROL TECHNOLOGY AND GENERAL SOURCE INSPECTION

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air Programs
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Research Triangle Park, North Carolina 27711

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The Field Operations and Enforcement Manual for Air Pollution Control, Volume II explains in detail the following: technology of source control, modification of operations, particulate control equipment, sulfur dioxide removal systems for power plants, and control equipment for gases and vapors; inspection procedures for general sources, fuel burning equipment, incinerators, open burning, odor detection and evaluation, and motor vehicle visible emissions.

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Stationary Source Pollution Control Programs
Research Triangle Park, North Carolina 27711

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The Field Operations and Enforcement Manual for Air Pollution Control is divided into three separate volumes.

Volume I, Organization and Basic Procedures, contains Chapters 1 through 4.

Volume II, Control Technology and General Source Inspection, contains Chapters 5 and 6.

Volume III, Inspection Procedures for Specific Industries, contains Chapter 7.

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CHAPTER 5
THE TECHNOLOGY OF SOURCE CONTROL

I. INTRODUCTION

The technology of source control consists of all of the sciences and techniques that can be brought to bear on the problem of controlling air pollution. These include the analysis and research that enter into determinations of technological and economic feasibility, planning and standard-setting as well as the application of specific hardware, fuels and materials with low emission potentials. Technology also includes the process of evaluating and upgrading the effectiveness of air pollution control practices. In this sense, the enforcement techniques described in this manual are an important part of the technology of source control.

At the heart of the control strategy process (see Chapter 1, Section IV) is the selection of the best air pollution control measures from among those available. To eliminate or reduce emissions from a polluting operation, four major courses of action are open:

- Eliminate the operation.
- Regulate the location of the operation.
- Modify the operation.
- Reduce or eliminate discharges from the operation by applying control devices and systems.

To achieve an acceptable atmosphere in a community requires a combination of these measures aimed at all or a major fraction of the contaminant sources within any control jurisdiction.

Control technology is self-defeating if it creates undesirable side-effects in meeting limited air pollution control objectives. Air pollution control should be considered in terms of both total technological systems and ecological consequences. The former considers the technology that can be brought to bear on controlling not only individual pieces of equipment, but whole technological systems. Consideration of ecological side-effects must take into account, for example, the problem of disposal by other means of possibly unmanageable accumulations of contaminants which are concentrated in the collection process, such as ground water pollution resulting from landfill practices or pollution of streams from the discharges of air pollution control systems.

II. ELIMINATION OF AIR POLLUTION OPERATIONS

An operation or activity can be eliminated only if it is unnecessary to those engaged in it or to the public, or if a reasonably satisfactory alternate exists. Thus, the prohibition of open burning and of single-chamber incinerators may depend on the availability of land for sanitary landfill, or the availability of approved multiple-chamber incinerators (see Chapter 6, Sections III and IV). Certain operations can be prohibited when they can be replaced by improved methods. For example, hand-firing of coal-burning installations can be prohibited in favor of automatic fuel-feeding systems; existing by-product core ovens can be prohibited in favor of systems or equipment using modified feed and product removal systems. Air pollution from motor vehicles could be drastically reduced by limiting their use if alternate, low-emission means of transportation were available. Thus, all control strategies which involve elimination of activities of a certain type must also provide for the institution of feasible alternate means of accomplishing the ends presently served by those activities.

Sources of air pollution can be eliminated by legislative fiat, i.e., by passage of a rule or regulation prohibiting a specific operation or type or design of equipment. These regulations are comparatively easy to enforce.

III. REGULATION OF LOCATION OF OPERATIONS

Alternative or supplementary approaches to air pollution control include: (1) applying zoning ordinances which cause the sources of air pollution to be located or distributed to minimize the effects of air pollution on receptors downwind and/or (2) imposing areal limits on emission rates that have been derived from air quality standard requirements. Both approaches may be implemented by regulatory standards, land-use planning and zoning controls and through the special handling of individual zone exception and land use permit cases. They can be useful in preventing potential public nuisance problems, reducing emission source densities and locating air pollution sources to make maximum use of the prevailing air flows of an area. The cooperation of urban planning, transportation and zoning agencies is required.

Zoning through legal sanctions is within the concept of the police power of the state, when sufficient evidence established through objective zoning studies can be presented. Air pollution zoning can be legally applied to prohibit new industries, limit expansion of existing industries, liquidate nonconforming industries after amortizing their existing investments, or eliminating existing harmful industries.

For many years planning commissions have recognized that smoke and other emissions from industrial sources would create less of a pollution potential for urban receptor areas if the emitting industries were located "downwind" of the metropolitan area. To take advantage of this possibility, the commission would select a location in one of the directions of most frequent air movement away from the city and designate land in that vicinity for an industrial district, where incentives to industrial development would be provided.

Another principle which is sometimes applied is that of buffer zoning, or isolation of a source of air pollution from potential effect areas by the creation of uninhabited areas around the source. Actual implementation of such plans will, of course, require close coordination between planning for public open land and planning for industrial development.

Enforcement officers can play a role in some phases of planning, particularly in the handling of zone exception cases. Enforcement personnel generally have intensive experience and knowledge of the nuisance potentials of specific types of industries, the community problems that are created and the economic and ecological relationships of an industry to its community and environment. In some agencies, enforcement officers are part of an inter-agency team that investigates zone exception cases (see Section VI E, Chapter 1).

IV. MODIFICATIONS OF OPERATIONS

The main thrust of current control technology is directed at hardware, fuels and materials. These are applied at appropriate points in the operational cycles of processes--from the preparation and charge of the feed (fuel, material and air) to the discharge of contaminated air and other waste products at the completion of the process cycle. This section describes examples of the many modifications that can be made to existing equipment and processes to help lessen emissions. Specific operational changes are further described in Chapters 6 and 7 in connection with specific equipment and processes of interest. Sections V and VI of this chapter describe the specific control devices that can be applied.

A. Change in Fuels or Process Materials

Frequently it is possible to reduce or eliminate certain contaminants from a particular process simply by substituting for the fuel or material customarily used another fuel or material having less contaminant emission potential.

The most obvious example is the use of low-sulfur fuels to replace high-sulfur coal or oil, much used in space-heating and in the generation of electric power. In the absence of equipment for removing the oxides of sulfur from stack gases, the emissions of sulfur oxides are proportional to the sulfur content of the fuels used.

According to the Environmental Protection Agency,(1) it is technically feasible to produce or desulfurize fuels to meet the following specifications: Distillate oil--0.1 percent sulfur (though it should be noted that distillate oil containing less than 0.2 percent sulfur is not generally available at this time); residual oil--0.3 percent sulfur; bituminous coal--0.7 percent sulfur.

Availability of significant quantities of such low-sulfur fuels in any region where they do not naturally occur or have not been imported from other domestic or foreign sources will require planning for the timely development of new sources of such fuels. Because residual oil generally is obtained from overseas sources, its use ordinarily is restricted to areas accessible to waterborne transportation. There are limited tonnages of 0.7 percent sulfur coal produced at the present time, primarily in the western United States. Large reserves of such coal exist but are not currently being mined.

In some cases, the sulfur content of coal may be substantially reduced by washing and pulverizing it. As much as 40 percent reduction in sulfur content in some coals may be obtained in this way, but this is not true of most types of coal. Methods for optimizing the use of limited supplies of low sulfur fuels include: (1) blending high and low sulfur grades, (2) storing low sulfur fuel and issuing it for use as a substitute for a high sulfur fuel when unfavorable weather conditions reduce the natural processes of atmospheric dilution and dispersion, (3) requiring high efficiency flue gas cleaning systems for large fuel users so they may burn high sulfur fuels safely, and then allocating the limited supply of low sulfur fuel to the large numbers of small users who discharge flue gases close to ground level and cannot operate flue gas cleaning systems economically.(2)

To reduce the emission of hydrocarbons from automobiles, one feasible measure is conversion to gaseous fuels--liquid natural gas (LNG) or liquid petroleum gas (LPG). To reduce the emission of particulate lead compounds from automobiles, the use of unleaded gasoline can be an effective measure.

To reduce emissions of organic solvents which have a high degree of reactivity in the development of oxidant-type smog, Los Angeles County devised a regulation (Rule 66) limiting the use of such solvents in large-scale operations. The regulation has been largely met by reformulation of industrial and architectural coatings.

Another example concerns the manufacture of paint brushes. When the bristles were bonded in rubber, the vulcanization process caused severe odor nuisances. The substitution of cold-setting resins for rubber completely eliminated such emissions.

In die casting, some molds are coated with mold release compounds containing oils or other volatile material. The heat from the molten metal vaporizes the oils, creating air contaminants. Recently mold release compounds have been developed that do not contain oils, and this source of air pollution is thereby eliminated.

B. Process and Facility Changes

In many operations, contaminant emissions can be eliminated or substantially reduced by changes in processes or facilities used to accomplish the operation.

Sometimes relatively small changes in the conditions under which a process is carried out may greatly reduce the quantity of contaminants the process usually produces. For example, in the control of fugitive dust, the liberal use of water to prevent dust emissions due to the action of the wind is a simple measure that can be employed in construction operations, grading of roads, land clearing, and the like. For dirt roads, asphalt or other materials may be applied to the same purpose. Again, in combustion of fossil fuels which contain sulfur, a substantial proportion of sulfur trioxide may occur in the stack gas when excess air of the order of 15 to 20 percent is used. This contaminant may be essentially eliminated by reducing excess air to less than 1 percent.(2)

Where it is not feasible to prevent mixing of contaminants with air, changes in process or facilities may reduce emission by restricting access of atmospheric air to the contaminant-producing operation. For example, open-bodied trucks may be covered when carrying dirt or other materials which can give rise to airborne dusts. Storage of volatile organic compounds, as in the petroleum industry, may be done in pressure tanks, or in tanks equipped with floating roofs. The chemical and petroleum refining industries have, in recent years, undergone radical changes in processing methods which emphasize continuous automatic operations, often computer-controlled, and completely enclosed systems that minimize release of materials to the atmosphere. Vapor recovery systems for transfer of gasoline at loading docks and filling stations and for prevention of evaporation losses from automobile fuel tanks belong in this category.

Where closed or covered systems for confining contaminants are impractical, it may be possible to collect the contaminated air or stack gas and to remove the contaminants from it while they are in a relatively concentrated form, before dispersion into the general atmosphere. It has been found possible, and often profitable, to control the loss of volatile materials by condensation and reuse of vapors, as by condensation units on tanks storing volatile petroleum products. For the handling of dusty materials, for sandblasting and spraying of materials that produce a dry particulate residue, installation and use of hoods, fans and fabric filters to enclose the process and prevent the escape of contaminated air may be effective. Hydrogen sulfide and mercaptans generated in petrochemical operations, if discharged through flares, are converted to oxides of sulfur. They may be absorbed from the gas stream and converted to elemental sulfur or sulfuric acid in a sulfur recovery plant. Emissions of carbon monoxide can be limited by requiring complete secondary combustion of waste gas generated in such operations as a grey iron cupola, blast furnace, regeneration of petroleum cracking catalysts, and others. In some instances, particularly in the petroleum industry, it is possible to utilize the heat produced by this secondary combustion, as in waste heat boilers.

To reduce or eliminate the pollution potential of a very objectionable operation, it may be to advantage to use an entirely different process to accomplish similar ends. Such changes, of course, are likely to require corresponding changes in facilities. As an example, the use of liquid and gaseous fertilizer chemicals (such as anhydrous ammonia), applied by injection into the earth, reduces pollution by eliminating the process of spreading fertilizers as finely divided powders, subject to entrainment by wind. For the disposal of solid waste, an adequate sanitary landfill system can replace the use of burning dumps or municipal incinerators, both of which may be prolific sources of combustion contaminants.

C. Improvements in Operational Practices

Even after control techniques have been applied to a process or system, emissions may be greater than necessary if the details of operation are not scrupulously observed. Careful evaluation of the sources of contaminants may in various cases reveal methods of operation which can alleviate persistent problems.

In food processing plants, odor problems can often be appreciably alleviated by housekeeping measures akin to those required for good sanitation. First(2) has reviewed some of the desirable procedures for use in the traditional "offensive trades," slaughtering, rendering, leather tanning, and pig farming, as well as in processes that handle food or inedible putrescible material. Processing steps such as storage of raw materials, grinding and other preparation of raw materials, cooking, oil extraction, drying of residues or products, are typical odor sources. Quick and adequate refrigeration of stored material is desirable. Plant design and maintenance should be conducive to good sanitation: all floors, walls and fixtures should be smooth, hard, and impervious to water so that they may be hosed down. Water for cleansing should contain residual chlorine to discourage microbiological activity. Surfaces should be pitched to drain the cleaning water to sumps for treatment. In heating vessels for cooking and drying, steam heating is preferred to direct flame units, in order to minimize local overheating and scorching of the organic material. (See Rendering Plants, Chapter 7, Section III.) Such practices minimize the emissions from processing vessels, reducing the load and therefore the efficiency demanded of the terminal odor incinerators or other control devices.

The effectiveness of any operational improvement depends upon continuing scrupulous attention to the procedures necessary to implement them. Thus, the use of water for the control of fugitive dust may represent a change in process for a given operation, but each application has a temporary effect. The change therefore must become a part of a continuous procedure. In other cases, frequent maintenance of process equipment or of control equipment is essential. As a general principle, it should be assumed that a control system is fully effective only when its operation and maintenance conforms to good practice. Field enforcement is primarily concerned with determining to what extent such good practice is being observed.

If the emissions from a given operation are observed to be substantially higher than those attainable (see Table 1.2) for any given operation, then improvements could be expected from the source, either by modernizing processes and equipment or by improving maintenance and operating practices.

Abnormally large emissions to the atmosphere may result from operating production equipment at excessive rates. For example, the output of the rotary sand and stone drier controls the production rate of hot mix asphalt plants. (See Asphaltic Batching Concrete Operations, Chapter 7, Section 8.) When the hot gas velocity through the drier is increased above the design rate, the quantity of dust emitted increases in greater proportion than the increase in gas flow. In the same industry, many air pollution problems stem from a customary practice of postponing maintenance procedures pending an annual shutdown. Machinery progressively declines in effectiveness during the operating season, resulting in cumulative unrepaired damage to dust collectors, exhaust systems, and equipment enclosures. For plants operating in this manner, intensive surveillance of emissions would be indicated, with increased frequency of maintenance measures required when control performance deteriorates.

Modification of unsatisfactory incinerators is usually practicable only if the changes required are relatively minor. Multiple-chamber incinerators may usually be operated satisfactorily, although this depends to some degree on the type of material charged. Use of the secondary burners is required occasionally to maintain the combustion efficiency of the secondary chamber. (See Incinerators, Chapter 6, Section III.)

In some operations, smoke abatement may be substantially a matter of adequate pre-processing of the material being burned. As noted previously, washing of coal may substantially reduce the emissions of ash, as well as oxides of sulfur in combustion operations. In reclaiming scrap metal from automobile bodies, great quantities of black smoke are sometimes generated by incineration. This can be avoided by first stripping the bodies of all fabric and upholstery, as well as rubber and plastic accessories. In the melting of scrap metal in steel manufacturing or foundry practice, much unnecessary smoke may be produced when oily scrap is charged into a melt. Such processes may be hooded and the effluent treated by incineration, or the oil and grease may be removed in a degreasing step, before the scrap enters the furnace.

V. SPECIFIC TYPES OF AIR POLLUTION CONTROL EQUIPMENT

A. Introduction

A major responsibility of field enforcement personnel is the inspection of the operation of air pollution control systems. The systems include hoods, ductwork, fans, compressors, gas conditioners and other auxiliary equipment needed for effective capture and conveying of the contaminant laden gases to the air pollution control equipment. Examples of specific types of air pollution control equipment applied to control specified contaminants are shown in Table 5.1.

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Aluminum Reduction Plants	Materials Handling Buckets & Belt Conveyor or Pneumatic Conveyor	Particulates (dust)	Exhaust Systems & Baghouse
	Anode & Cathode Electrode Prep. Cathode Baking	Hydrocarbon Emissions from Binder	
	Anodes Grinding & Blending	Particulates (dust)	Exhaust Systems & Mechanical Collectors
	Baking	Particulates (dust), CO, SO_2, Hydrocarbons & Fluorides	Hi-eff. Cyclone, Elect. Prec., Scrubbers, Catalytic Combustion or Incinerators, Flares, Baghouse
	Pot Charging	Particulates (dust), CO, HF, SO_2, CF_4, & Hydrocarbons	Hi-eff. Cyclone, Baghouse, Spray Towers, Floating Bed Scrubber, Elect. Prec., Chemisorption, Wet Elect. Prec.
	Metal Casting	Cl_2, HCl, CO & Particulates (dust)	Exhaust Systems & Scrubbers

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Asphalt Batch Plants	Materials Handling, Storage & Classifiers Elevators Chutes Vibrating Screens	Particulates (dust)	Local Exhaust Systems with a Cyclone Precleaner & a Scrubber or Baghouse
	Drying Rotary Oil or Gas Fired	Particulates & Smoke	Proper Combustion Controls, Fuel Oil Preheating where Required; Local Exhaust System, Cyclone & a Scrubber or Baghouse
	Truck Traffic	Dust	Wetting down Truck Routes
Cement Plants	Quarrying Primary Crusher, Secondary Crusher, Conveying, Storage	Particulates (dust)	Wetting, Exhaust Systems with Mechanical Collectors
	Dry Processes Materials Handling, Air Separator (Hot Air Furnace)	Particulates (dust) Particulates (dust)	Local Exhaust System & Mechanical Collectors & Baghouse

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Cement Plants (continued)	Grinding	Particulates (dust)	Local Exhaust System with Cyclones & Baghouse
	Pneumatic, Conveying & Storage	Particulates (dust)	
	Wet Process Materials Handling Grinding Storage	Wet Materials, No Dust	
	Kiln Operations Rotary Kiln	Particulates (dust), CO, SO_x, NO_x, Hydrocarbons, Aldehydes, Ketones	Elect. Prec. & Baghouses, Scrubber, Flare
	Clinker Cooling Materials Handling	Particulates (dust)	Local Exhaust System & Mechanical Collectors
	Grinding & Packaging Air Separator Grinding Pneumatic Conveying Materials Handling Packaging	Particulates (dust)	Local Exhaust Systems & Mechanical Collectors

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Coal Preparation Plants	Materials Handling Conveyors Elevators Chutes	Particulates (dust)	Local Exhaust Systems & Cyclones
	Sizing Crushing Screening Classifying	Particulates (dust)	Local Exhaust Systems & Cyclones
	De-Dusting	Particulates (dust)	Local Exhaust System, Cyclone Precleaners & Baghouse
	Storing Coal in Piles	Blowing Particulates (dust)	Wetting, Plastic Spray Covering
	Refuse Piles	H_2S, Particulates and Smoke from Burning Storage Piles	Digging out Fire, Pumping Water onto Fire Area, Blanket with Incombustible Material
	Coal Drying Rotary, Screen, Suspension, Fluid Bed, Cascade	Dust, Smoke, Particulates, Sulfur Oxides, H_2S	Exhaust Systems with Cyclones & Packed Towers on Venturi Scrubbers

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Coke Plants	By-Product Ovens Charging	Smoke, Particulates (dust)	Pipeline Charging, Careful Charging Techniques; Portable Hooding & Scrubber or Baghouses
	Pushing	Smoke, Particulates (dust) SO_2	Minimize Green Coke Pushing - Need for Collection Techniques
	Quenching	Smoke, Particulates (dust & mists), Phenols & Ammonia	Baffles & Spray Tower
	By-Product Processing	CO, H_2S, Methane, Ammonia, H_2, Phenols, Hydrogen Cyanide, N_2, Benzene, Xylene, etc.	Elect. Prec., Scrubber, Flaring
	Material Storage (coal & coke)	Particulates (dust)	Wetting, Plastic Spray, Fire Prevention Techniques
Fertilizer Industry (Chemical)	Phosphate Fertilizers Crushing, Grinding & Calcining	Particulates (dust)	Exhaust System, Scrubber, Cyclone Baghouse
	Hydrolysis of P_2O_5	PH_3, P_2O_5, H_3PO_4 mist	Scrubbers, flare

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Fertilizer Industry (Chemical) (continued)	Acidulation & Curing	HF, SiF_4	Scrubbers
	Granulation	Particulates (dust) (product recovery)	Exhaust System, Scrubber or Baghouse
	Ammoniation	NH_3, NH_4Cl, SiF_4, HF	Cyclone, Elect. Prec., Baghouse, High Energy Scrubber
	Nitric Acid Acidulation	NO_x, Gaseous Fluoride Compounds	Scrubber, Addition of Urea
	Superphosphate Storage & Shipping	Particulates (dust)	Exhaust System, Cyclone or Baghouse
	Ammonium Nitrate Reactor	NH_3, NO_x	Scrubber
	Prilling Tower	NH_4, NO_3	Proper Operation Control

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Foundries	Melting (cupola)		
Iron	Charging Melting Pouring	Smoke & Particulates Smoke & Particulates, Fume, Oil, Mist, CO	Closed Top with Exhaust System, CO Afterburner, Gas-cooling Device & Baghouse or Elect. Prec., Wetting to Extinguish Fire
	Bottom Drop	Smoke & Particulates	
Brass Bronze	Melting Charging Melting Pouring	Smoke, Particulates, Oil Mist Zinc Oxide Fume, Particulates, Smoke, Zinc Oxide Fume, Lead Oxide Fume	Low Zinc Content Red Brass: Use Good Combustion Controls & Slag Cover. High Zinc Content Brass: Use Good Combustion Controls, Local Exhaust System & Baghouse
Aluminum	Melting Charging Melting Pouring	Smoke & Particulates	Charge Clean Material (no paint or grease) Proper Operation should be Required. No Air Pollution Control Equipment if no Fluxes are Used & Degassing is not required. Dirty Charge Requires Exhaust System with Scrubbers & Baghouses
Zinc	Melting Charging	Smoke & Particulates	Exhaust System with Cyclone and Baghouse. Charge Clean Material (no paint or grease)
	Melting Pouring	Zinc Oxide Fume Oil Mist & Hydrocarbons from Die Casting Machines	Careful Skimming of Dross Use Low Smoking Die Casting Lubricants

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Foundries (continued)	Sand Handling Shakeout	Particulate (dust), Smoke Organic Vapors	
	Magnetic Pully Conveyors & Elevators Rotary Cooler Screening Crusher Mixer	Particulates (dust)	Exhaust System, Cyclone & Baghouse
	Core Making Ovens	Organic Acids, Aldehydes, Smoke, Hydrocarbons	Use of Binders that will Allow Ovens to Operate at Less than 400°F or Exhaust Systems & Afterburners
Galvanizing Operations	Hot Dip Galvanizing Tank Kettle Dipping Material into the Molten Zinc. Dusting Flux onto the Surface of the Molten Zinc.	Fumes, Particulates (liquid), Vapors - NH_4Cl, ZnO, $ZnCl_2$, Zn, NH_3, Oil, & C	Close Fitting Hoods with High Indraft Velocities (in some cases the hood may not be able to be close to the kettle so that the indraft velocity must be very high) Baghouses, Elect. Prec.

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Kraft Pulp Mills	Digesters Batch & Continuous	Mercaptans, Methanol (odors)	Condensers & Use of Lime Kiln, Hog Fuel Boiler or Furnaces as After-burners
	Multiple Effect Evaporators	H_2S, Other Odors	Caustic-Scrubbing & Thermal Oxidation of Non-Condensibles
	Recovery Furnace	H_2S, Mercaptans, Organic Sulfides & Disulfides	Paper Combustion Controls for Fluctuating Load & Unrestricted Primary & Secondary Air Flow to Furnace & Elect. Prec.
	Weak & Strong Black Liquor Oxidation	H_2S	Packed Tower & Cyclone
	Smelt Tanks	Particulates (mist or dust)	Demisters, Venturi, Packed Tower or Impingement Type Scrubbers
	Lime Kiln	Particulates (dust), H_2S	Venturi Scrubbers
Municipal & Industrial Incinerators	Single Chamber Incinerators	Particulates, Smoke, Volatiles, CO, SO_x, Ammonia, Organic Acids, Aldehydes, NO_x, Hydrocarbons, Odors, HCl	
	Flue Fed		Settling Chambers, Scrubbers, Afterburner, By-pass Flue, Ash Cleanout

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Municipal & Industrial Incinerators (continued)	Multiple Chamber Incinerators Retort, Inline	Particulates, Smoke and Combustion Contaminants	Operating at Rated Capacity, Using Auxiliary Fuel as Specified & Good Maintenance including Timely Clean-out of Ash
	Flue Fed	Particulates, Smoke and Combustion Contaminants	Use of Charging Gates & Automatic Controls for Draft
	Wood Waste	Particulates, Smoke and Combustion Contaminants	Continuous Feed Systems, Operate at Design Load & Excess Air, Limit Charging of Oily Material
	Municipal Incinerators 50-100 tons/day	Particulates, Smoke, Volatiles, CO, Ammonia, Organic Acids, Aldehydes, NO_x, Hydrocarbons, SO_x, Hydrogen Chloride, Odors	Preparation of Materials Including Weighing, Grinding, Shredding; Control of Tipping Area, Furnace Design with Proper Automatic Controls; Proper Startup Techniques; Maintenance of Design Operating Temperatures; use of Scrubbers & Baghouses; Proper Ash Cleanout
	Pathological Incinerators	Odors, Hydrocarbons	Proper Charging
	Wood Waste & Industrial Waste	Particulates, Smoke and Combustion Contaminants	Modified Fuel Feed, Auxiliary Fuel & Dryer Systems
	Box Type	Particulates, Smoke and Combustion Contaminants	Allow Proper Startup, Charge Material Slowly, Don't Overload

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Non-Ferrous Smelters, Primary			
Copper	Roasting	SO_2, Particulates, Fume	Exhaust System, Settling Chambers, Cyclones or Scrubbers & Elect. Prec. for Dust & Fumes & Sulfuric Acid Plant for SO_2.
	Reverberatory Furnace	Smoke, Particulate, Fume, SO_2	Exhaust System, Settling Chambers, Cyclones or Scrubbers & Elect. Prec. for Dust & Fumes & Sulfuric Acid Plant for SO_2
	Converters Charging Slag Skim Pouring Air or Oxygen Blow	Smoke, Fume, SO_2	Exhaust System, Settling Chambers, Cyclones or Scrubbers, Elect. Prec. for Dust & Fumes & Sulfuric Acid Plant for SO_2
Lead	Sintering	SO_2, Particulates, Smoke	Exhaust System, Cyclones & Baghouse or Precipitators for Dust & Fumes, Sulfuric Acid Plant for SO_2
	Blast Furnace	SO_2, CO, Particulates Lead Oxide, Zinc Oxide	Exhaust System, Settling Chambers, Afterburner & Cooling Device, Cyclone & Baghouse

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Lead (continued)	Dross Reverberatory Furnace	SO_2, Particulates, Fume	Exhaust System, Settling Chambers, Cyclone & Cooling Device, Baghouse
	Refining Kettles	SO_2, Particulates	Local Exhaust System, Cooling Device Baghouse or Precipitator
Cadmium	Roasters, Slag, Fuming Furnaces, Deleading Kilns	Particulates	Local Exhaust System, Baghouse or Precipitator
Zinc	Roasting	Particulates (dust) & SO_2	Exhaust System, Humidifier, Cyclone Scrubber, Elect. Prec. & Acid Plant
	Sintering	Particulates (dust) & SO_2	Exhaust System, Humidifier, Elect. Prec. & Acid Plant
	Calcining	Zinc Oxide Fume, Particulates, SO_2, CO	Exhaust System, Baghouse
	Retorts Electric Arc		
Non-Ferrous Smelters, Secondary	Blast Furnaces & Cupolas - Recover Metal from Scrap & Slag	Dust, Fumes, Particulates, Oil Vapor, Smoke, CO	Exhaust Systems, Cooling Devices, CO Burners & Baghouses or Precipitators

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Non-Ferrous Smelters, Secondary (continued	Reverberatory Furnaces	Dust, Fumes, Particulates, Smoke, Gaseous Fluxing Materials	Exhaust Systems & Baghouses, or Precipitators or Venturi Scrubbers
	Crucible Furnaces	See Non-Ferrous Foundries	
	Sweat Furnaces	Smoke, Particulates Fumes	Precleaning Metal & Exhaust Systems with Afterburner & Baghouse
	Wire Reclamation & Autobody Burning	Smoke, Particulates	Scrubbers & Afterburners
Paint & Varnish Mfg.	Resin Mfg. Closed Reaction Vessel	Acrolein, Other Aldehydes & Fatty Acids (odors) Phthalic Anhydride (subl.)	Exhaust System with Scrubbers & Fume Burners
	Varnish Cooking - Open or Closed Vessels	Ketones, Fatty Acids, Formic Acids, Acetic Acid, Glycerine, Acrolein, Other Aldehydes, Phenols & Terpenes; From Tall Oils, Hydrogen Sulfide, Alkyl Sulfide, Butyl Mercaptan & Thiofene (odors)	Exhaust System with Scrubbers & Fume Burners - Close Fitting Hoods are Required for Open Kettles
	Solvent Thinning	Olefins, Branches Chain Aromatics & Ketones (odors), Solvents	Exhaust System with Fume Burners

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Rendering Plants	Feed Stock Storage & Housekeeping	Odors	Quick Processing, Washdown of All Concrete Surfaces, Pave Dirt Roads, Proper Sewer Maintenance
	Cookers & Percolators	SO_2, Mercaptans, Ammonia, Odors	Exhaust System, Condenser, Scrubber or Incinerator
	Grinding	Particulates (dust)	Exhaust System & Scrubber
Roofing Plants (Asphalt Saturators)	Felt or Paper Saturators Spray Section Asphalt Tank Wet Looper	Asphalt Vapors & Particulates (liquid)	Exhaust System with High Inlet Velocity at Hoods (> 200 ft/min) with Either Spray Scrubbers, Baghouses or Two Stage Low Voltage Elect. Prec.
	Crushed Rock or Other Minerals Handling	Particulates (dust)	Local Exhaust System, Cyclone or Multiple Cyclones
Steel Mills	Blast Furnaces Charging, Pouring	CO, Fumes, Smoke Particulates (dust)	Good Maintenance, Seal Leaks; Use of Higher Ratio of Pelletized or Sintered Ore; CO Burned in Waste Heat Boilers, Stoves or Coke Ovens; Cyclone, Scrubber, Elect. Prec. or Venturi Scrubber

Table 5.1. CONTROL TECHNIQUES APPLICABLE TO UNIT PROCESSES AT IMPORTANT EMISSION SOURCES (continued)

INDUSTRY	PROCESS OF OPERATION	AIR CONTAMINANTS EMITTED	CONTROL TECHNIQUES
Steel Mills (continued)	Electric Steel Furnaces Charging, Pouring, Oxygen Blow	Fumes, Smoke, Particulates (dust), CO	Segregate Dirty Scrap; Proper Hooding, Baghouses, Venturi Scrubbers, or Elect. Prec.
	Open Hearth Furnaces Oxygen Blow, Pouring	Fumes, Smoke, SO_x, Particulates, (dust), CO, NO_x	Proper Hooding, Settling Chambers, Waste Heat Boiler, Baghouse, Elect. Prec. or Venturi Scrubber
	Basic Oxygen Furnaces Oxygen Blowing	Fumes, Smoke, CO, Particulates, (dust)	Proper Hooding (capture emissions & dilute CO) Scrubbers or Elect. Prec.
	Raw Material Storage	Particulates (dust)	Wetting or Application of Plastic Spray
	Pelletizing	Particulates (dust)	Proper Hooding, Cyclone, Baghouse
	Sintering	Smoke, Particulates (dust), SO_2, NO_x	Proper Hooding, Cyclones, Venturi Scrubbers, Baghouse or Precipitator

These include all industries dealt with in this manual with the exception of petroleum refineries, chemical plants, construction and demolition activities, and mining which are treated more fully in Chapters 6 and 7.

This section of the document describes air pollution control devices in use by industry to reduce particulates where they are produced in quantities sufficient to come under the provisions of most air pollution control agencies. Part E of this section, fabric systems, in particular, describes inspection points common to most air pollution control systems. Section VII of this chapter describes sulfur dioxide removal systems for power plants and Section VIII describes control systems for gases and vapors.

Equipment used to reduce the emission of air contaminants is selected on the basis of collection efficiency. The factors which affect the design of the equipment are:

- Particle size range.
- Concentration of particles in the gas stream.
- Physical and chemical characteristics of the contaminants.

Table 5.2 represents an overview of particulate collectors in common use by industry. Figure 5.1 shows theoretical collection efficiencies vs. particle sizes for families of collectors.

B. Gravitational Settling Chambers

Gravitational settling chambers, commonly known as settling chambers or balloon ducts are the simplest devices used to collect dust of large particle sizes. This is accomplished by reducing the velocity of the carrier gas and allowing the dust to "settle" by gravity. As the horizontal velocity of the particle decreases due to an increase

Table 5.2. USE OF PARTICULATE COLLECTORS BY INDUSTRY

Industrial classification	Process	EP	MC	FF	WS	Other
Utilities and industrial power plants	Coal	0	0	----	----	----
	Oil	0	0	----	----	----
	Natural gas	----	----	----	----	----
	Lignite	0	0	----	----	----
	Wood and bark	+	0	----	+	----
	Bagasse	----	0	----	----	----
	Fluid coke	0	+	----	----	+
Pulp and paper	Kraft	0	----	----	0	----
	Soda	0	----	----	0	----
	Lime kiln	----	----	----	0	----
	Chemical	----	----	----	0	----
	Dissolver tank vents	----	0	----	----	+
Rock products	Cement	0	0	0	+	----
	Phosphate	0	0	0	0	----
	Gypsum	0	0	0	0	----
	Alumina	0	0	0	+	----
	Lime	0	0	+	----	----
	Bauxite	0	0	----	----	----
	Magnesium oxide	+	+	----	----	----
Steel	Blast furnace	0	----	----	0	+
	Open hearth	0	----	----	+	+
	Basic oxygen furnace	0	----	----	0	----
	Electric furnace	+	----	0	0	----
	Sintering	0	0	----	----	----
	Coke ovens	0	----	----	----	+
	Ore roasters	0	0	----	+	----
	Cupola	+	----	+	0	----
	Pyrites roaster	0	0	----	0	----
	Taconite	+	0	----	----	----
	Hot scarfing	0	----	----	+	----
Mining and metallurgical	Zinc roaster	0	0	----	----	----
	Zinc smelter	0	----	----	----	----
	Copper roaster	0	0	----	----	----
	Copper reverb	0	----	----	----	----
	Copper converter	0	----	----	----	----
	Lead furnace	----	----	0	0	----
	Aluminum	0	----	----	0	+
	Elemental phos	0	----	----	----	----
	Ilmenite	0	0	----	----	----
	Titanium dioxide	+	----	0	----	----
	Molybdenum	+	----	----	----	----
	Sulfuric acid	0	----	----	0	0
	Phosphoric acid	----	----	----	0	0
	Nitric acid	----	----	----	0	0
	Ore beneficiation	+	+	+	+	+

Table 5.2. USE OF PARTICULATE COLLECTORS BY INDUSTRY (continued)

Industrial classification	Process	EP	MC	FF	WS	Other
Miscellaneous	Refinery catalyst	0	0	----	----	----
	Coal drying	----	0	----	----	----
	Coal mill vents	----	+	0	----	----
	Municipal incinerators	+	0	----	0	+
	Carbon black	+	+	+	----	----
	Apartment incinerators	----	----	----	0	----
	Spray drying	----	0	0	+	----
	Machining operation	----	0	0	+	+
	Hot coating	----	----	----	0	0
	Precious metal	0	----	0	----	----
	Feed and flour milling	----	0	0	----	----
	Lumber mills	----	0	----	----	----
	Wood working	----	0	0	----	----

Key:
0 = Most common
+ = Not normally used
EP = Electrostatic Precipitator
MC = Mechanical Collector
FF = Fabric Filter
WS = Wet Scrubber

Other = Packed towers
Mist pads
Slag filter
Centrifugal exhausters
Flame incineration
Settling chamber

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

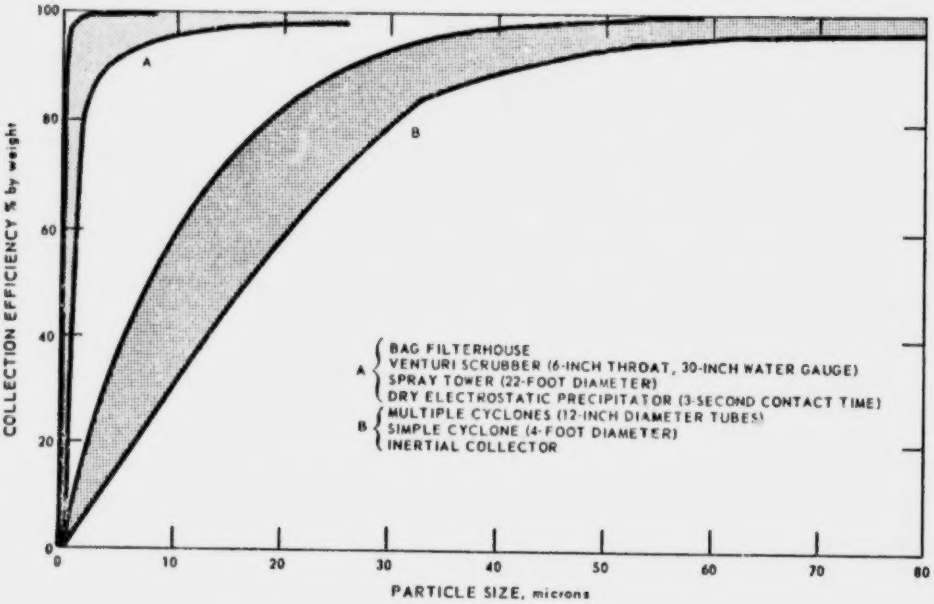


Figure 5.1. COMPOSITE GRADE (FRACTIONAL) EFFICIENCY CURVES BASED ON TEST SILICA DUST (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

in the cross-sectional area of the chamber (1 to 10 feet per second) the larger particles, >43 microns,(3) will tend to settle to the bottom of the chamber (Table 5.3).(4) These devices are usually used as precleaners and may form a part of a gas cleaning and cooling train upstream of higher efficiency collectors.

Since settling chambers are usually precleaners and serve to remove large particles and sometimes cool gases, the enforcement officer may not be able to determine the effectiveness of the device until the more efficient collectors downstream begin to show loss of efficiency by a change in the opacity or color of the effluent. Removal of captured material from the bottom of the chamber is essential to its effectiveness. Where chain or screw conveyors are used to remove the particulates it is easy to find out if they are in operation. During an inspection, the operator of the equipment can be requested to open the door of the hopper to see if it has been recently cleaned. Maintenance is also important since air leaks can alter the pickup of the dust collection points.

C. Cyclone Separators

Cyclone is a common name for the centrifugal separator. The cyclone is a closed device consisting of a cylinder on top of an inverted cone. Dust-laden air enters through a tangential duct at the top of the cylinder. The velocity of the air, as governed by a blower motor in the ductwork causes the particles to be separated from the air stream by centrifugal deflection. This is accomplished by means of the double vortex principle (Figure 5.2) in which the dust-laden gases spiral down the walls of the cyclone and then move up the inside of the spiral after losing particles due to centrifugal force. The particles slide down the walls of the cyclone into a hopper while the cleaned gases escape through a tube at the top of the cylinder.

Table 5.3. SETTLING VELOCITIES OF SPHERICAL PARTICLES OF UNIT DENSITY IN AIR

Temperature: 20°C(68°F): Pressure 760mm Hg.

Particle diameter microns	Experimental cm/sec	Calculated from Stokes' law cm/sec
0·1	$8{\cdot}7 \times 10^{-5}$	$8{\cdot}71 \times 10^{-5}$
0·2	$2{\cdot}3 \times 10^{-4}$	$2{\cdot}27 \times 10^{-4}$
0·4	$6{\cdot}8 \times 10^{-4}$	$6{\cdot}85 \times 10^{-4}$
1·0	$3{\cdot}5 \times 10^{-3}$	$3{\cdot}49 \times 10^{-3}$
2	$1{\cdot}19 \times 10^{-2}$	$1{\cdot}19 \times 10^{-2}$
4	$5{\cdot}0 \times 10^{-2}$	$5{\cdot}00 \times 10^{-2}$
10	$3{\cdot}06 \times 10^{-1}$	$3{\cdot}06 \times 10^{-1}$
20	1·2	1·2
40	4·8	5
100	24·6	25
400	157	483
1000	382	3050

(SOURCE: OFFICE OF MANPOWER DEVELOPMENT, Reference 4)

This device ranges from a simple cyclone to a mechanically driven device such as the American Air Filter dynamic cyclone. Depending on the gas condition, particle size range and dust loading (also liquid particles) cyclones can be used singly (Figure 5.2) or in parallel (Figures 5.3 and 5.4). They can be designed with either tangential inlets or straight flow-through passages.

High efficiency tangential inlet cyclones are characterized by a narrow inlet opening to attain a high inlet velocity, long body length relative to body diameter, and a small outlet diameter relative to the body diameter. Higher collection efficiencies result from the increased energy expended due to the high inlet velocities. High throughput cyclones have larger inlet openings and larger gas exits. Figures 5.5 and 5.6 show the geometrical relationships for these types of cyclones.

All of the dimensions of a cyclone are related to its largest inside diameter. These ratios were derived from experimental dimensional analysis for optimum collection of particulates based upon particle size and grain loading. High efficiency cyclones therefore are long and thin (sometimes called pencil cyclones) while the high throughput and lower efficiency cyclones have a squat appearance.

Cyclones are in common use in many industrial operations as both primary gas cleaners and precleaners. Many pneumatic conveying systems use some form of centrifugal separator to remove the product from the conveying medium. Food and grain handling processes, hot asphalt plants, cement plants, chemical plants and petroleum refineries use some configuration of centrifugal separators.

Table 5.4 shows applications of cyclone collectors. Table 5.5 describes representative performances of these collectors. Table 5.6 describes collection efficiencies relative to particle size.

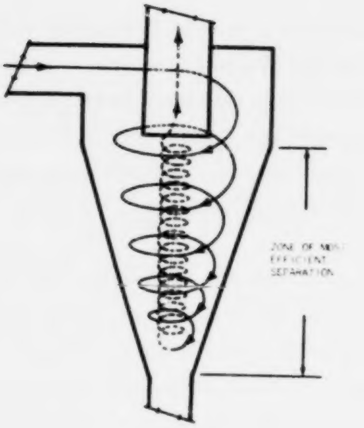


Figure 5.2. DOUBLE-VORTEX PATH OF THE GAS STREAM IN A CYCLONE.

(SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

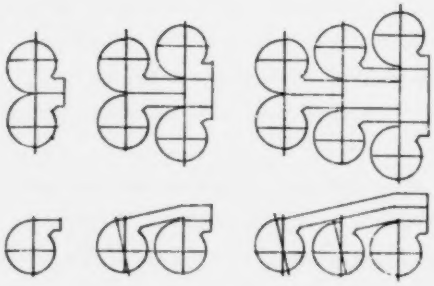


Figure 5.3. CYCLONES ARRANGED IN PARALLEL, COURTESY OF BUELL ENGINEERING COMPANY, INC.

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

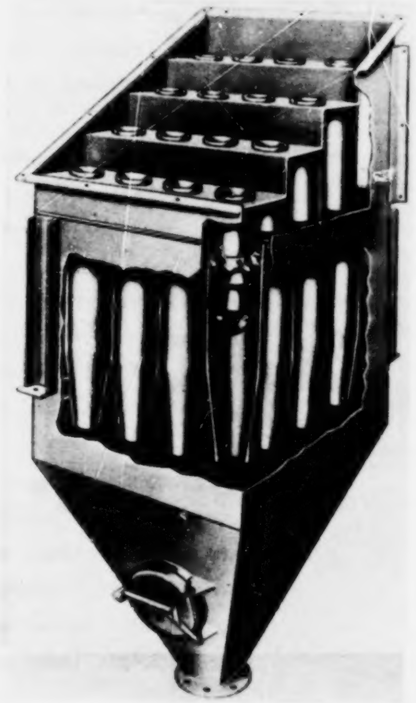


Figure 5.4. CYCLONES ARRANGED IN PARALLEL, COURTESY OF WESTERN PRECIPITATION DIVISION

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

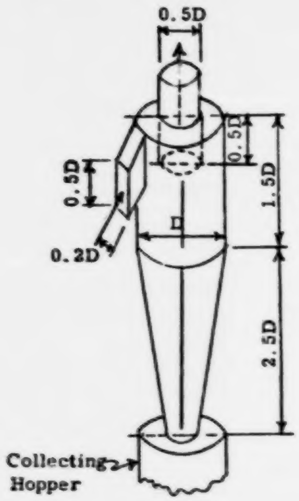

0.5D
0.5D
0.5D
1.5D
D
0.2D
2.5D
Collecting Hopper

Figure 5.5. HIGH EFFICIENCY CYCLONE (SOURCE: OFFICE OF MANPOWER DEVELOPMENT, Reference 4)

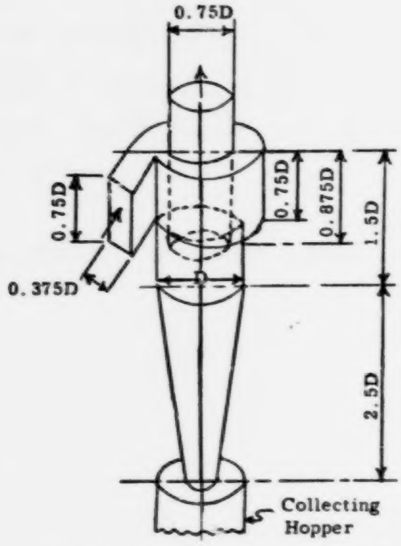

0.75D
0.75D
0.75D
0.875D
1.5D
0.375D
D
2.5D
Collecting Hopper

Figure 5.6. HIGH THROUGHPUT CYCLONE (SOURCE: OFFICE OF MANPOWER DEVELOPMENT, Reference 4)

Table 5.4. APPLICATIONS OF CENTRIFUGAL COLLECTORS

Operation or process	contaminant	Type of air cleaning equipment	Collector efficiency, wt percent
Crushing, pulverizing, mixing, screening:			
Alfalfa feed mill	Alfalfa dust	Cyclone, settling chamber.	85
Barley feed mill	Barley flour dust	Cyclone	85
Wheat air cleaner	Chaff	Cyclone	85
Drying, baking:			
Catalyst regenerator (petroleum)	Catalyst dust	Cyclone, ESP	95
Detergent powder spray drier	Detergent powder	Cyclone	85
Orange pulp feed drier	Pulp dust	Cyclone	85
Sand drying kiln	Silica dust	Cyclone	78
Sand and gravel drying	Silica dust	Inertial collector	50
Stone drying kiln	Silica dust	Cyclone	86
Mixing fluids:			
Asphalt mixing	Sand and gravel dust	Cyclone	50–86
Bituminous concrete mixing	Sand and stone dust	Cyclone, scrubber	95
Polishing, buffing, grinding, chipping:			
Grinding (aluminum)	Aluminum dust	Cyclone	89
Grinding (iron)	Iron scale and sand	Cyclone	56
Grinding (machine shop)	Dust	Impeller collector	91
Surface coating rubber dusting	Fluffy zinc stearate	Impeller collector	78–88
Surface treatment—physical:			
Abrasive cleaning	Talc dust	Cyclone	93
Abrasive stick trimming and shaping.	Silicon carbide and alumina dust.	2 parallel cyclones	51
Casting cleaning with metal shot, sandblasting and tumbling.	Metallic and silica dust	Impeller collector	97–99+
Foundry tumbling	Dust	Impeller collector	99
Truing and shaping abrasive products.	Silicon carbide and alumina dust.	Cyclone	58
Woodworking, including plastics rubber, paper board: mill planing.	Wood dust and chips	Cyclone	97

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

Table 5.5. REPRESENTATIVE PERFORMANCE OF CENTRIFUGAL COLLECTORS

Collector type	Process	Material	Airflow, ft³/min	Pressure drop, in. H_2O	Efficiency, wt percent	Inlet load, gr/ft³	Inlet mass median size, μ
Series cyclone	Fluid-catalytic cracking.	Catalyst	40,000	High	99.98	2800	37.0
Cyclone	Abrasive cleaning	Talc	2,300	0.33	93.0	2.2	--------
Cyclone	Drying	Sand and gravel	12,300	1.9	86.9	38.0	8.2 [a]
Cyclone	Grinding	Aluminum	2,400	1.2	89.0	0.7	--------
Cyclone	Planing mill	Wood	3,100	3.7	97.0	0.1	--------
Impeller collectors.	Grinding	Iron scale	11,800	4.7	56.3	0.15	3.2 [b]
Impeller collectors.	Rubber dusting	Zinc stearate	3,300	9.0	88.0	0.6	0.7

[a] Outlet mass median size = 3.2 microns.
[b] Outlet mass median size = 2.5 microns.

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

Table 5.6. COLLECTION EFFICIENCY RELATIVE TO PARTICLE SIZE

Particle size (μ)	Efficiency (% by wt.)	
	Conventional cyclone	High efficiency cyclone
Less than 5	--	50 - 80
5 - 20	50 - 80	80 - 90
15 - 50	80 - 95	95 - 99
40	95 - 99	95 - 99

(SOURCE: OFFICE OF MANPOWER DEVELOPMENT, Reference 4)

1. Inspection Points

Problems that affect the collection efficiency of cyclones which an enforcement officer must recognize are:

- Buildup of dust on the cyclone walls and at the bottom of the cone resulting in clearly visible dust emissions in the exhaust gas.
- Plugging of the inlet duct which causes sufficient back pressure to decrease dust pickup or dust conveying upstream of the cyclone.
- Increase in the humidity of the conveying gas which will cause particle agglomeration and plugging.
- Air leaks caused by holes will change the pressure drop across the cyclone adversely affecting its efficiency.
- An increase in dust loading or a decrease in particle size or density will adversely affect the collection efficiency.
- Improper application of cyclones as dust collectors.

The efficiency of these types of collectors drops rapidly for particle sizes below 5μ. They are most effective for particle sizes ranging from 10 to 200μ.(3)

D. Scrubbers (Wet Collectors)

The mechanisms for wet collection of particulates are:

(1) Wetting the particle by contact with a liquid droplet. This occurs by impingement of fine droplets (100μ optimum) on dust particles, deposition of the dust particles on collector plates and by diffusion and condensation of the carrier gas by cooling it below its dew point.

(2) Impingement of the wet particles on a collecting surface and removal by flushing.

As with all collection equipment, particle size distribution and operating conditions will be the determining factors in the selection of a particular wet collector for a specific air pollution control application. The scrubber efficiency is a function of the power input. As an example, venturi scrubbers can have pressure drops exceeding 70" W.G. (inches of water) where small particle sizes and high grain loadings are involved.

Wet collectors are classified as:(3)

(1) Gravity spray towers (Figure 5.7).
(2) Centrifugal spray scrubbers (Figure 5.8).
(3) Impingement plate scrubbers (Figure 5.9).
(4) Venturi scrubbers (Figures 5.10, 5.11, 5.12).
(5) Packed bed scrubbers (Figures 5.13, 5.14, 5.15).
    (a) cross flow
    (b) countercurrent flow
    (c) parallel flow
    (d) flooded-bed
    (e) fluid-bed
(6) Self-induced spray scrubbers (Figure 5.16).
(7) Mechanically induced spray scrubbers (Figure 5.17).
(8) Disintegrator scrubbers.
(9) Centrifugal fan wet scrubbers (Figure 5.18).
(10) Inline wet scrubbers (Figure 5.19).
(11) Irrigated wet filters (Figure 5.20).

Due to the almost endless variety of scrubbers it is difficult to generalize relationships among such operating parameters as pressure drop and liquid flow rate. Manufacturer's data covering the specific piece of equipment of interest is the best source of this data. Table 5.7 gives ranges of water-to-gas ratios and pressure drops for the most common types of scrubbers in use. The efficiency of Venturi scrubbers depends on the pressure drop and can be improved by increasing the gas velocity or the water injection rate. Venturi scrubbers as a class of wet collectors are effective for collecting particles smaller than 2 μ. Figure 5.21 shows a set of curves relating the percentage of contaminant collection efficiency to

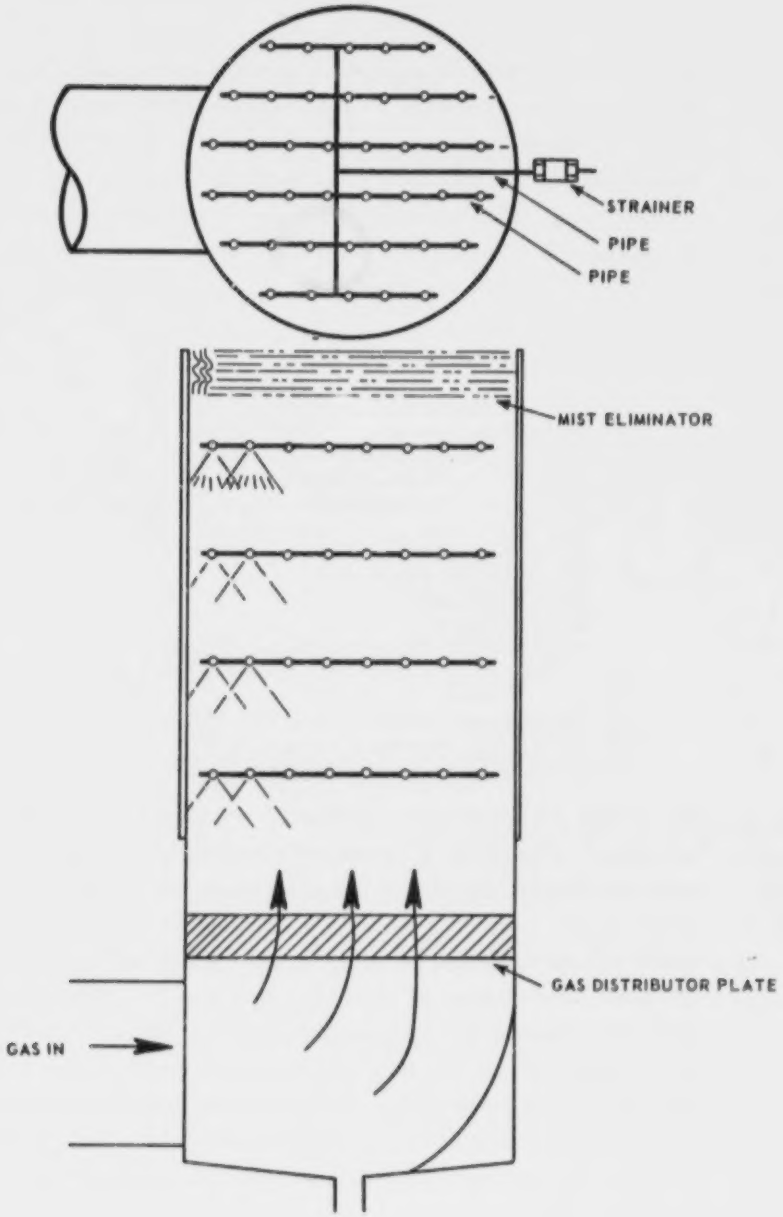
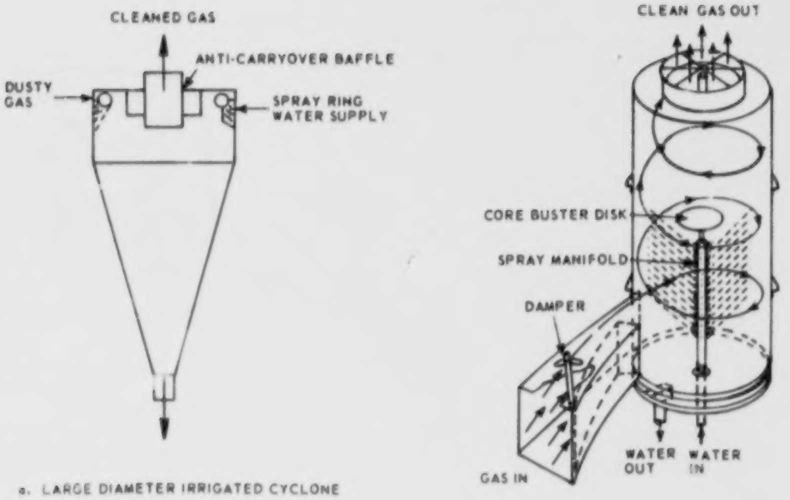
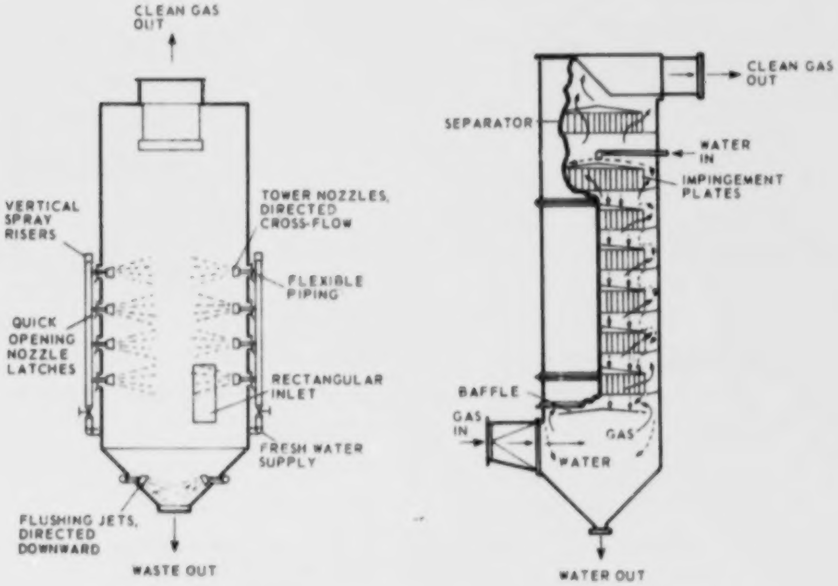

STRAINER
PIPE
PIPE
MIST ELIMINATOR
GAS DISTRIBUTOR PLATE
GAS IN

Figure 5.7. TYPICAL LAYOUT FOR GRAVITY SPRAY TOWER, COURTESY OF SPRAYING SYSTEMS COMPANY (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)


CLEANED GAS
ANTI-CARRYOVER BAFFLE
DUSTY GAS
SPRAY RING WATER SUPPLY
CLEAN GAS OUT
CORE BUSTER DISK
SPRAY MANIFOLD
DAMPER
GAS IN
WATER OUT
WATER IN

a. LARGE DIAMETER IRRIGATED CYCLONE

b. PEASE ANTHONY CYCLONIC SCRUBBER
(Courtesy of Chemical Construction Corporation)


CLEAN GAS OUT
VERTICAL SPRAY RISERS
TOWER NOZZLES, DIRECTED CROSS-FLOW
FLEXIBLE PIPING
QUICK OPENING NOZZLE LATCHES
RECTANGULAR INLET
FRESH WATER SUPPLY
FLUSHING JETS, DIRECTED DOWNWARD
WASTE OUT
CLEAN GAS OUT
SEPARATOR
WATER IN
IMPINGEMENT PLATES
BAFFLE
GAS IN
GAS
WATER
WATER OUT

c. CYCLONIC SPRAY SCRUBBER.
(Courtesy of Buffalo Forge Company)

d. MULTI-WASH SCRUBBER.
(Courtesy of Claude B. Schneible Company)

Figure 5.8. CENTRIFUGAL SPRAY SCRUBBERS (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

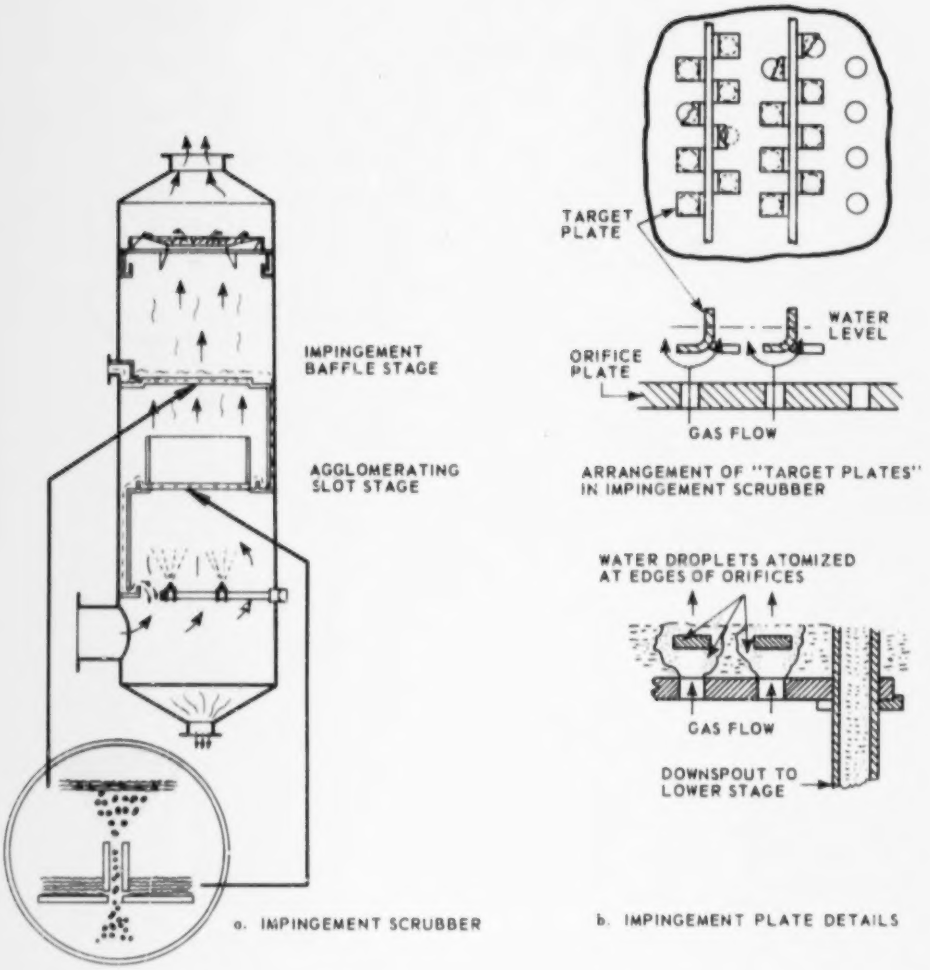

IMPINGEMENT
BAFFLE STAGE
AGGLOMERATING
SLOT STAGE
a. IMPINGEMENT SCRUBBER
TARGET
PLATE
WATER
LEVEL
ORIFICE
PLATE
GAS FLOW
ARRANGEMENT OF "TARGET PLATES"
IN IMPINGEMENT SCRUBBER
WATER DROPLETS ATOMIZED
AT EDGES OF ORIFICES
GAS FLOW
DOWNSPOUT TO
LOWER STAGE
b. IMPINGEMENT PLATE DETAILS

Figure 5.9. IMPINGEMENT PLATE SCRUBBER (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

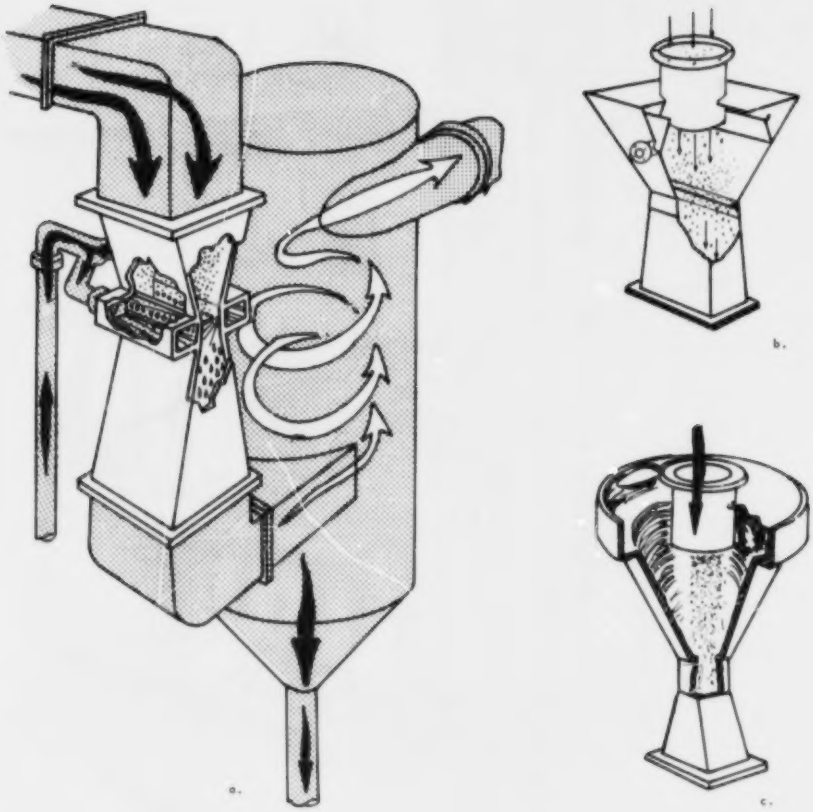


Figure 5.10. VENTURI SCRUBBER MAY FEED LIQUID THROUGH JETS (a), OVER A WEIR (b), OR SWIRL THEM ON A SHELF (c), COURTESY OF UOP AIR CORRECTION DIVISION (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

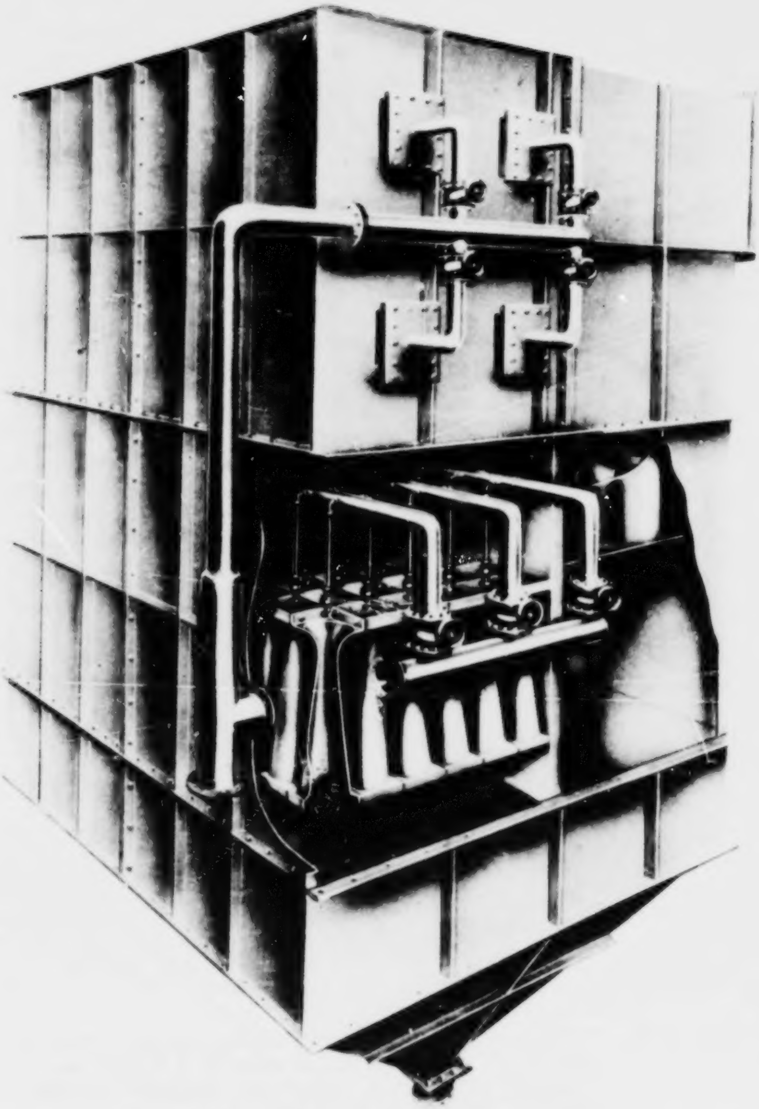


Figure 5.11. MULTIPLE-VENTURI JET SCRUBBER, COURTESY OF BUELL CORPORATION (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

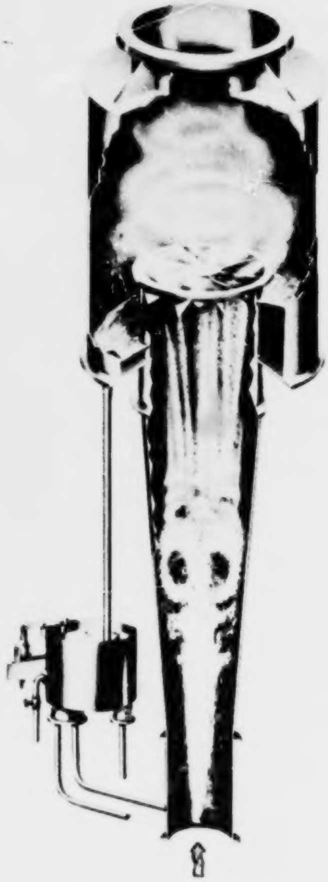
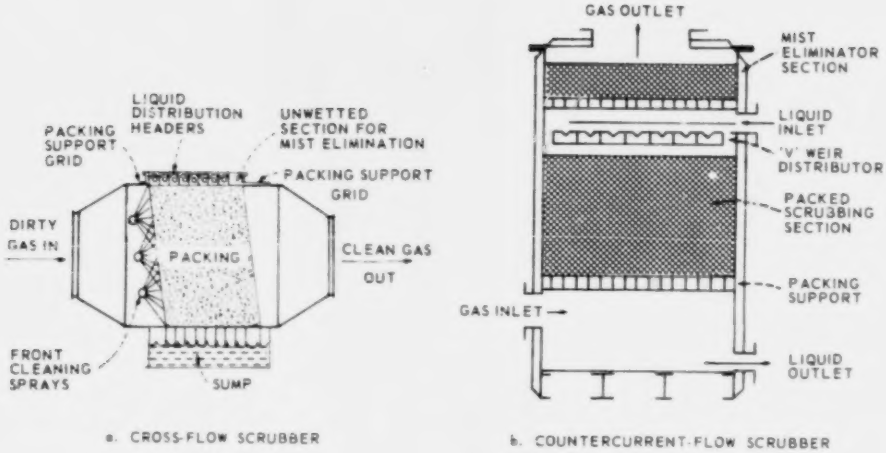


Figure 5.12. VERTICAL VENTURI SCRUBBER, COURTESY OF UOP AIR CORRECTION DIVISION (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)


LIQUID DISTRIBUTION HEADERS
PACKING SUPPORT GRID
UNWETTED SECTION FOR MIST ELIMINATION
PACKING SUPPORT GRID
DIRTY GAS IN
PACKING
CLEAN GAS OUT
FRONT CLEANING SPRAYS
SUMP
GAS OUTLET
MIST ELIMINATOR SECTION
LIQUID INLET
'V' WEIR DISTRIBUTOR
PACKED SCRUBBING SECTION
PACKING SUPPORT
GAS INLET
LIQUID OUTLET

a. CROSS-FLOW SCRUBBER

b. COUNTERCURRENT-FLOW SCRUBBER

Figure 5.13. PACKED-BED SCRUBBERS, COURTESY OF CHEMICAL ENGINEERING MAGAZINE (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

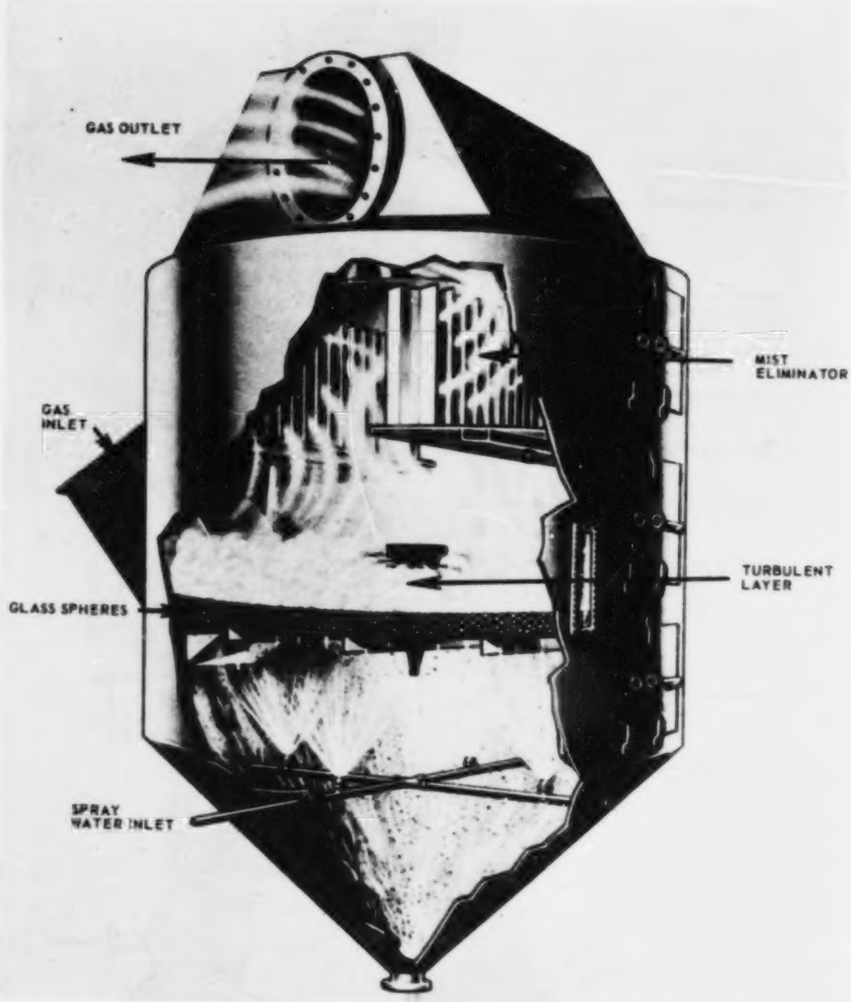

GAS OUTLET
MIST ELIMINATOR
GAS INLET
TURBULENT LAYER
GLASS SPHERES
SPRAY WATER INLET

Figure 5.14. FLOODED-BED SCRUBBER, COURTESY OF NATIONAL DUST COLLECTOR CORPORATION (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

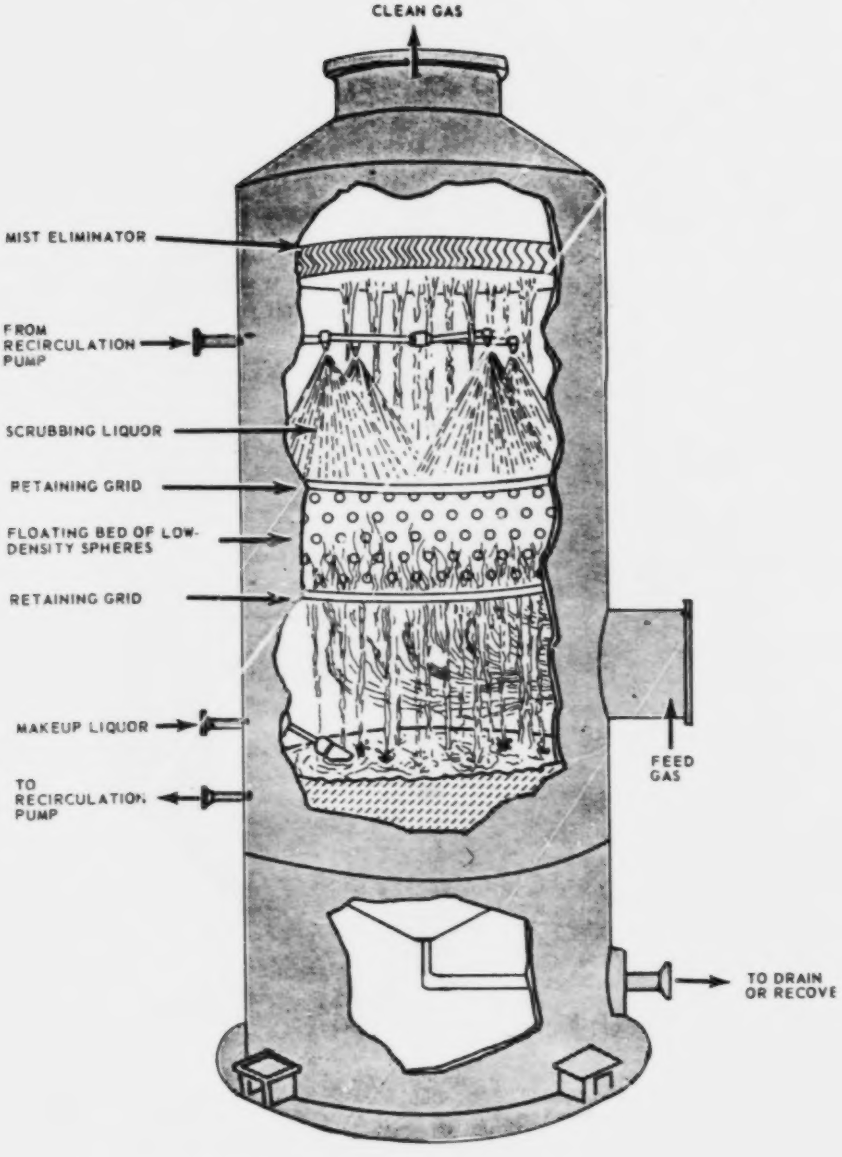
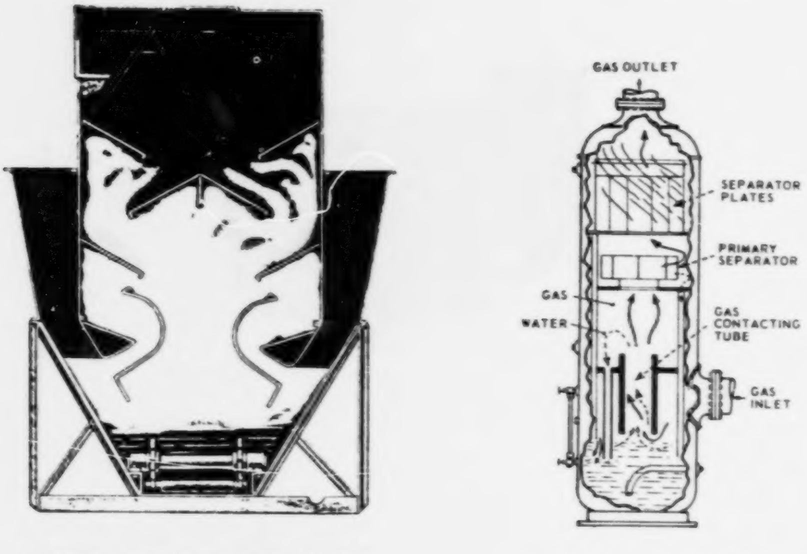
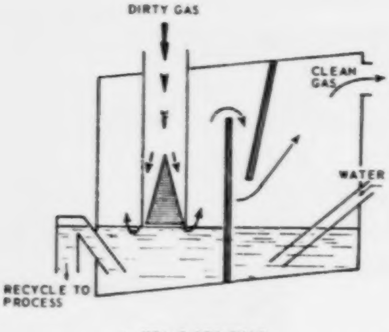

CLEAN GAS
MIST ELIMINATOR
FROM RECIRCULATION PUMP
SCRUBBING LIQUOR
RETAINING GRID
FLOATING BED OF LOW-DENSITY SPHERES
RETAINING GRID
MAKEUP LIQUOR
TO RECIRCULATION PUMP
FEED GAS
TO DRAIN OR RECOVE

Figure 5.15. FLOATING-BALL (FLUID-BED) PACKED SCRUBBER,
COURTESY OF UOP AIR CORRECTION DIVISION
(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)


GAS OUTLET
SEPARATOR PLATES
PRIMARY SEPARATOR
GAS
WATER
GAS CONTACTING TUBE
GAS INLET

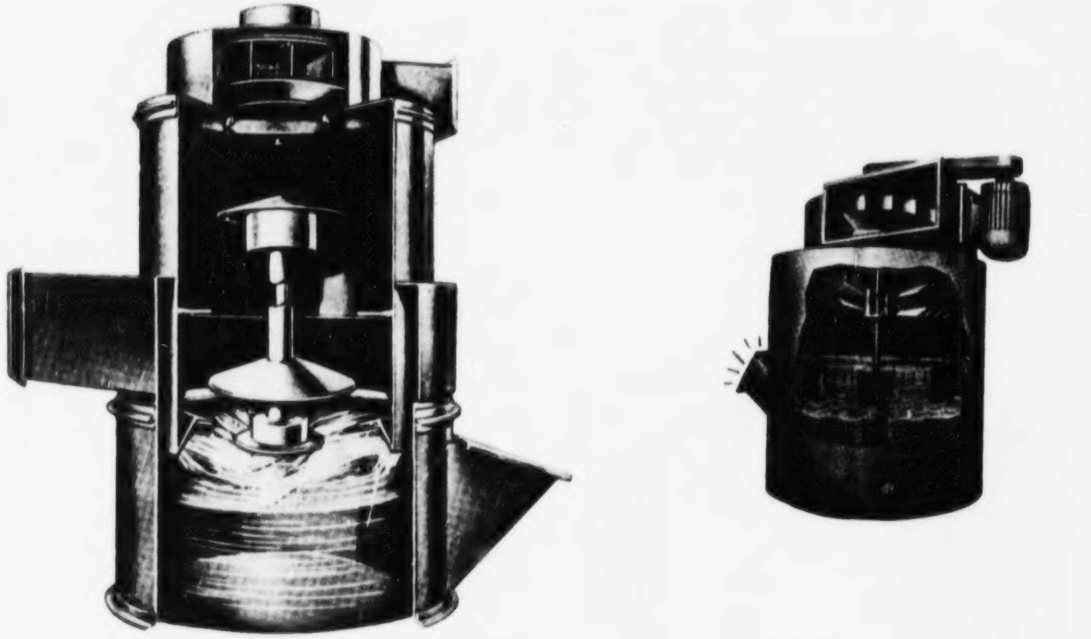
a. SCHMIEG SWIRL-ORIFICE DUST COLLECTOR
(Courtesy of United Sheet Metal Co., Inc.)

b. LIQUID VORTEX CONTRACTOR
(Courtesy of Blaw Knox Co.)


DIRTY GAS
CLEAN GAS
WATER
RECYCLE TO PROCESS

c. DOYLE SCRUBBER
(Courtesy of Western Precipitation Division)

Figure 5.16. SELF-INDUCED SPRAY SCRUBBERS (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)



a. SCHMIEG VERTICAL-ROTOR DUST COLLECTOR
(Courtesy of United Sheet Metal Co., Inc.)

b. CENTER SPRAY HIGH-VELOCITY SCRUBBER
(Courtesy of Air Engineering Magazine)

Figure 5.17. MECHANICALLY INDUCED SPRAY SCRUBBERS (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

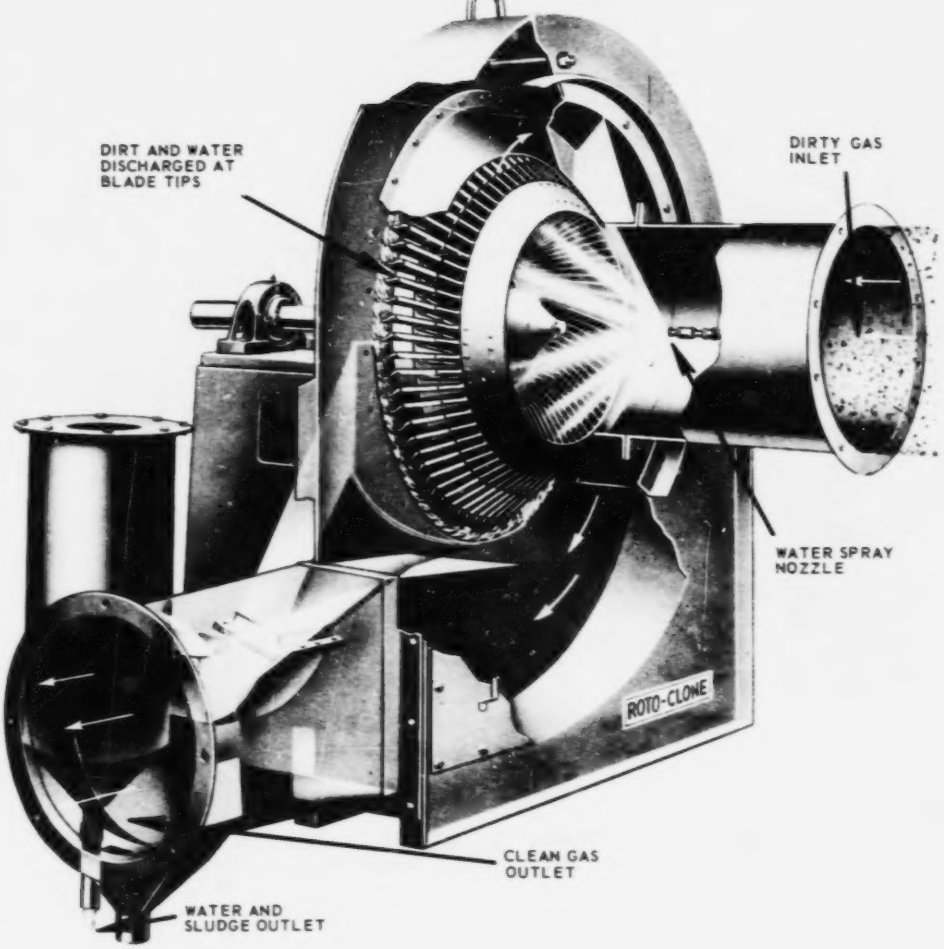

DIRT AND WATER DISCHARGED AT BLADE TIPS
DIRTY GAS INLET
WATER SPRAY NOZZLE
ROTO-CLONE
CLEAN GAS OUTLET
WATER AND SLUDGE OUTLET

Figure 5.18. CENTRIFUGAL FAN WET SCRUBBER, COURTESY OF AMERICAN AIR FILTER COMPANY (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

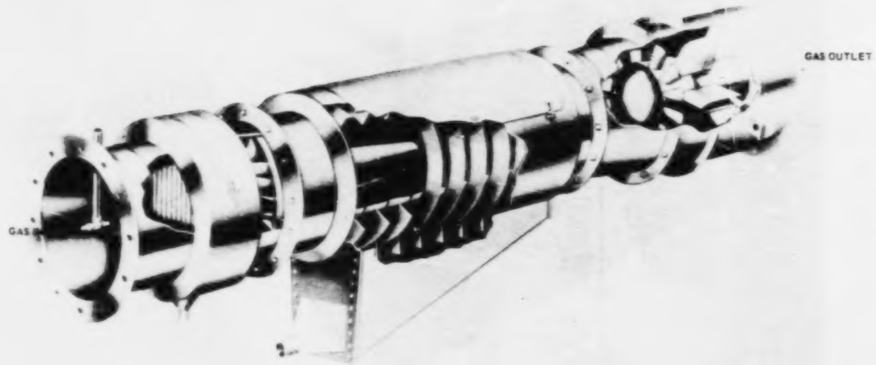
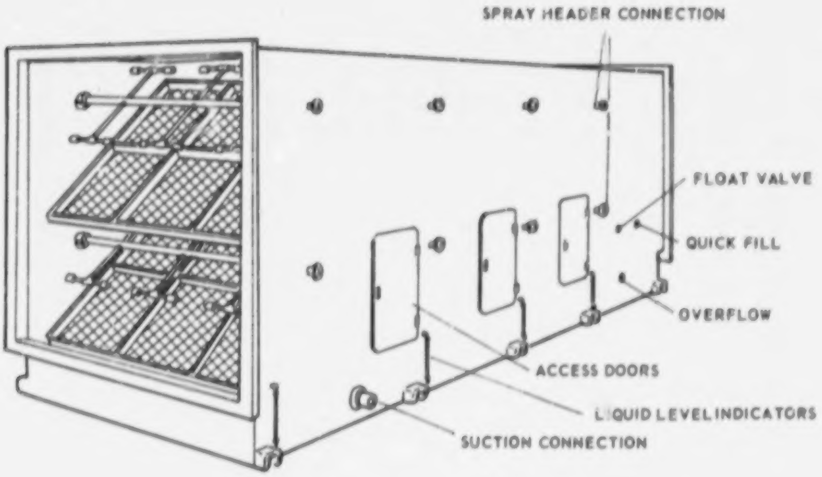
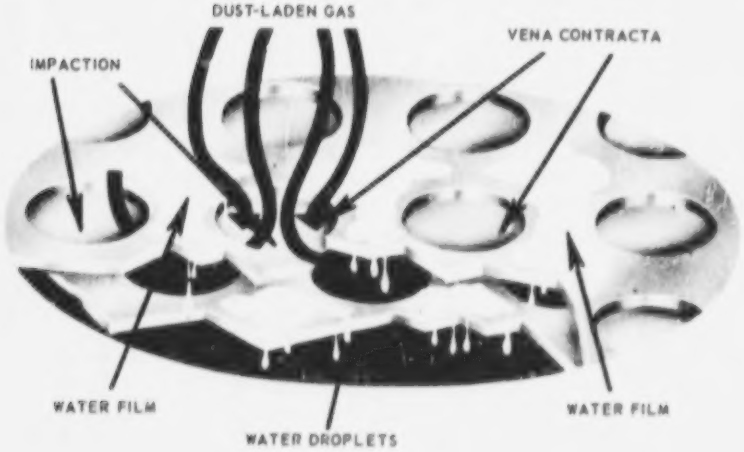

GAS OUTLET
GAS

Figure 5.19. INLINE WET SCRUBBER, COURTESY OF JOY MANUFACTURING COMPANY (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)


SPRAY HEADER CONNECTION
FLOAT VALVE
QUICK FILL
OVERFLOW
ACCESS DOORS
LIQUID LEVEL INDICATORS
SUCTION CONNECTION

a. WETTED FILTER


DUST-LADEN GAS
VENA CONTRACTA
IMPACTION
WATER FILM
WATER DROPLETS
WATER FILM

b. IMPINGEMENT PLATE FILTER

Figure 5.20. WETTED AND IMPINGEMENT PLATE FILTERS, COURTESY OF BUFFALO FORCE COMPANY (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

Table 5.7. WET SCRUBBER OPERATIONAL CHARACTERISTICS
(Compiled from References 3 and 6.)

Scrubber Type	Gas Velocity Range Ft/Sec	Water to Gas Ratio Gal/1000 CFM	Gas Flow vs, Spray Direction			Pressure Drop in W.G.
			Counter-Current	Concurrent	Right Angle	
Gravity Spray Towers	2 to 5	5 to 20	✓			< 1.0
Centrifugal Spray Scrubber	UP to 200	5 to 15	✓		✓	1.5 to 3.5
Impingement Plate Scrubber	75 to 100	3 to 5		✓		1.0 to 8.0
Venturi Scrubbers	200 to 600	5 to 7		✓		6.0 to 70.0
Packed Bed Scrubbers						
a. Cross Flow	9 to 17	1 to 4			✓	0.2 to 0.5/ ft bed
b. Countercurrent Flow	9 to 17	10 to 20	✓			0.5 to 1.0/ ft bed
c. Parallel Flow	9 to 17	7 to 15		✓		1.0 to 4.0/ ft bed
d. Flooded-Bed	9 to 17	2 to 2-1/2	✓			4.0 to 6.0
e. Fluid-Bed	9 to 17	3 to 5	✓			4.0 to 8.0
Self-Induced Spray Scrubbers	50 to 180	No pumping				2.0 to 15.0
Mechanically Induced Spray Scrubbers	33 to 66	4 to 5			✓	[3 to 10 HP]
Disintegrating Scrubbers	33 to 66	4 to 9			✓	[7 to 11 HP]
Centrifugal Fan Wet Scrubbers	33 to 66	.75 to 1.5			✓	6.5 to 9.0
Inline Wet Scrubbers	33 to 50	1			✓	5.0
Irrigated Wet Filters	3.3 to 5.0	8 to 10			✓	0.2 to 3.0

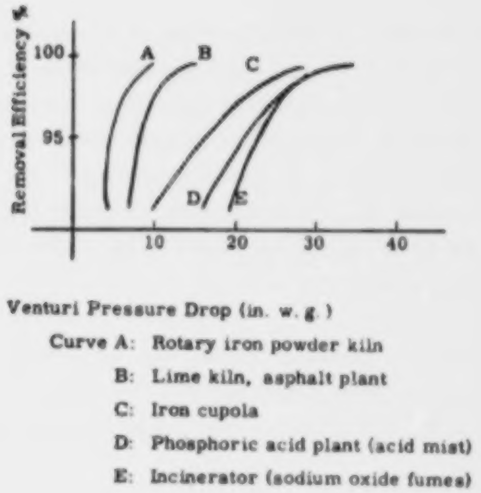


Figure 5.21. COLLECTION EFFICIENCY VS. PRESSURE DROP IN VENTURI SCRUBBERS (PAGE 3, SECTION ON VENTURI SCRUBBERS, INSTITUTE FOR A.P. TRAINING, CONTROL OF PART). (SOURCE: Reference 4)

pressure drop. Other types of scrubbers lose efficiency rapidly when particle sizes drop below 3 microns.

Another critical area in the selection of a scrubber for a specific application of dust control is the concentration of particulates in the gas stream. Effluent streams with heavy concentrations of dust and relatively large particle size should first be treated in a precleaner such as a cyclone or settling chamber. The dust-laden gas then can be cleaned by a scrubber with the proper design characteristics for the types of particulates, grain loading and particle sizes to be collected.

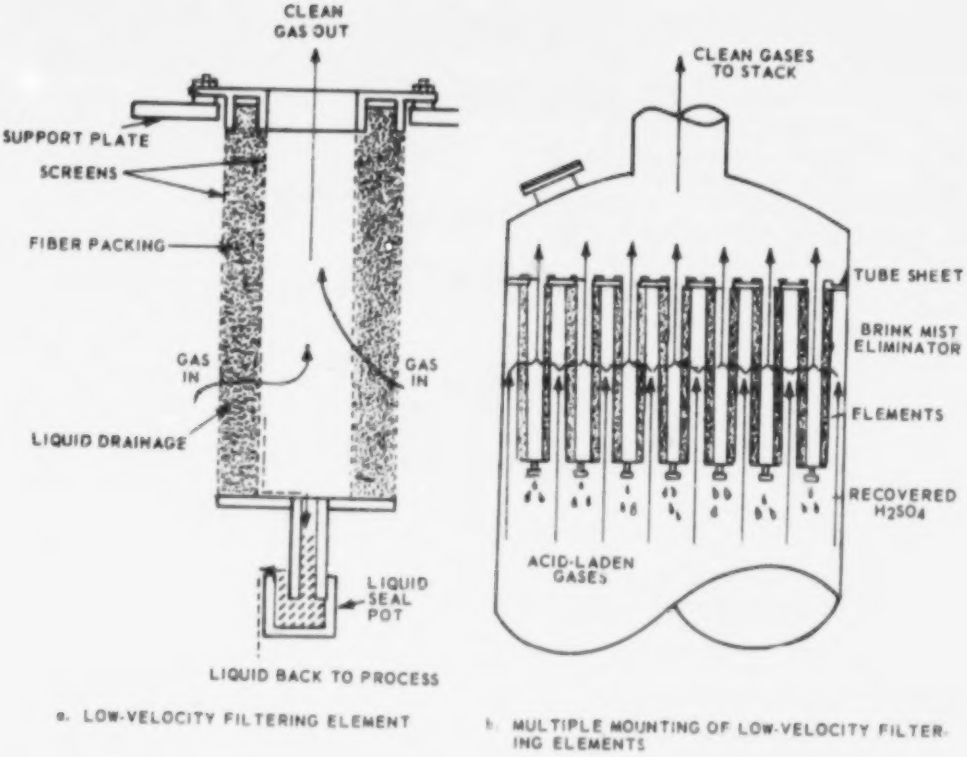
Demisters while not generally classified as primary collectors are used in conjunction with scrubbers for the capture of large diameter liquid and solid particulates. The types of demisters are:

Fiber filters	Figure 5.22
Wire Mesh	Figure 5.23
Baffles	Figure 5.24
Packed Beds	Figure 5.25

These devices depend on inertial impaction for control of large size particles ($> 10\ \mu$). Table 5.8 shows the typical applications for the various types of mist eliminators. Pressure drops on fiber filter demisters range from 5 to 15 inches of water. Pressure drops on other types of demisters tend to be lower and range from 1 to 5 inches of water.

1. Inspection Points

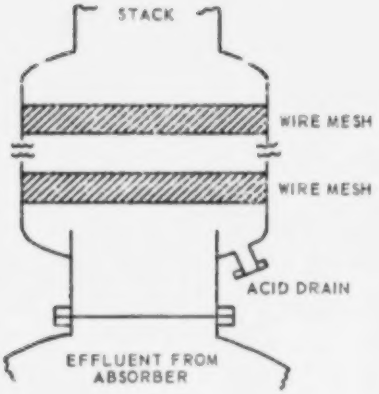
In addition to observing the color, opacity and carryover after the dissipation of water vapor from the scrubber, the enforcement officer must be aware of its operating characteristics and


CLEAN GAS OUT
SUPPORT PLATE
SCREENS
FIBER PACKING
GAS IN
GAS IN
LIQUID DRAINAGE
LIQUID SEAL POT
LIQUID BACK TO PROCESS
CLEAN GASES TO STACK
TUBE SHEET
BRINK MIST ELIMINATOR
FLEMENTS
RECOVERED H2SO4
ACID-LADEN GASES

a. LOW-VELOCITY FILTERING ELEMENT

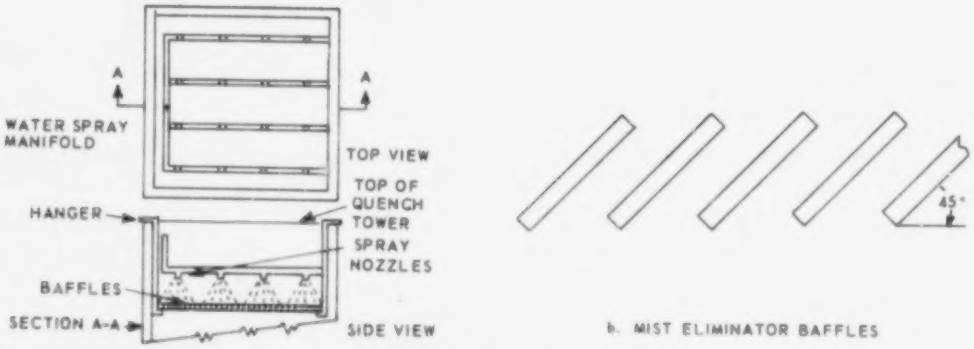
b. MULTIPLE MOUNTING OF LOW-VELOCITY FILTERING ELEMENTS

Figure 5.22. LOW-VELOCITY FILTERING ELEMENTS (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)


STACK
WIRE MESH
WIRE MESH
ACID DRAIN
EFFLUENT FROM
ABSORBER

MIST ELIMINATOR ARRANGEMENT IN VESSEL ABOVE ACID PLANT ABSORBER
(Courtesy of Chemical Engineering Progress Magazine)

Figure 5.23. WIRE MESH MIST ELIMINATOR


A
A
WATER SPRAY
MANIFOLD
TOP VIEW
TOP OF
QUENCH
TOWER
HANGER
SPRAY
NOZZLES
BAFFLES
SECTION A-A
SIDE VIEW
45°

b. MIST ELIMINATOR BAFFLES

a. DIAGRAM OF BAFFLE SYSTEM SHOWING CLEANING WATER SPRAYS AND BAFFLE ARRANGEMENT

Figure 5.24. COKE QUENCH MIST ELIMINATION BAFFLE SYSTEM

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

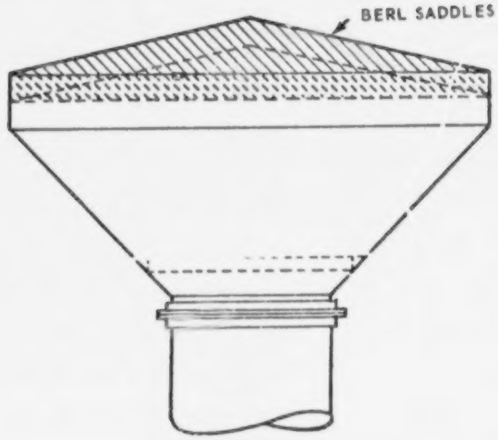

BERL SADDLES

Figure 5.25. BED OF BERL SADDLES ADDED TO DISCHARGE STACK
(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

Table 5.8. TYPICAL INDUSTRIAL APPLICATION OF WET SCRUBBERS

Scrubber type	Typical application
Spray chambers	Dust cleaning, electroplating, phosphate fertilizer, kraft paper, smoke abatement
Spray tower	Precooler, blast furnace gas
Centrifugal	Spray dryers, calciners, crushers, classifiers, fluid bed processes, kraft paper, fly ash
Impingement plate	Cupolas, driers, kilns, fertilizer, flue gas
Venturi:	
Venturi throat	Pulverized coal, abrasives, rotary kilns, foundries, flue gas, cupola gas, fertilizers, lime kilns, roasting, titanium dioxide processing, odor control, oxygen steel making, coke oven gas, fly ash
Flooded disk	
Multiple jet	
Venturi jet	Fertilizer manufacture, odor control, smoke control
Vertical venturi	Pulverized coal, abrasive manufacture
Packed bed:	
Fixed	Fertilizer manufacturing, plating, acid pickling
Flooded	Acid vapors, aluminum inoculation, foundries, asphalt plants, atomic wastes, carbon black, ceramic frit, chlorine tail gas, pigment manufacture, cupola gas, driers, ferrite, fertilizer
Fluid (floating) ball	Kraft paper, basic oxygen steel, fertilizer, aluminum ore reduction, aluminum foundries, fly ash, asphalt manufacturing
Self-induced spray	Coal mining, ore mining, explosive dusts, air conditioning, incinerators
Mechanically-induced spray	Iron foundry, cupolas, smoke, chemical fume control, paint spray
Disintegrator	Blast furnace gas
Centrifugal fan Inline fan	Metal mining, coal processing, foundry, food, pharmaceuticals
Wetted filters	Electroplating, acid pickling, air conditioning, light dust
Dust, mist eliminators:	
Fiber filters	Sulfuric, phosphoric, and nitric acid mists; moisture separators; household ventilation; radioactive and toxic dusts, oil mists
Wire mesh	Sulfuric, phosphoric, and nitric acid mists; distillation and absorption
Baffles	Coke quenching, kraft paper manufacture, plating
Packed beds	Sulfuric and phosphoric acid manufacture, electroplating spray towers

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

physical characteristics. Inspection points include:

(1) A check for structural wear from corrosion.

(2) Recording the water pressure to the scrubber to compare it with the design pressure.

(3) An inspection of the interior of the scrubber to see if there are deposits of material which could disturb the flow pattern.

(4) Noting impairment in efficiency due to freezing.

(5) Establishing the maintenance schedule for cleaning and replacing nozzles.

(6) Noting the operation of fans and pumps and fraying or excessively worn drive belts.

(7) Noting if the bypass system has been opened and the duration of the time of bypass.

(8) Recording temperature and pressure of gases entering the scrubber to check against design parameters.

Table 5.8 describes applications of scrubbers by industrial process. Since venturi scrubbers are among the high efficiency collectors, additional descriptive performance data is included in Table 5.9.

E. Fabric Filters

Most often referred to as baghouses, fabric filters remain among the most efficient air pollution control equipment for small size particulates ($< 0.01\ \mu$).(3) Dust-laden gases are forced through a fabric bag which may be tubular or flat (Figures 5.26 and 5.27) where the particulates are retained by direct interception, inertial impaction, diffusion, electrostatic attraction and gravitational settling.

Gases to be cleaned can either be "pushed" through or "pulled" through the baghouse. In the pressure system (push through) the

Table 5.9. TYPICAL PERFORMANCE DATA FOR VENTURI SCRUBBER*

Source of Gas	Contaminants	Approximate Size Range (Microns)	Loading (Grains/ cf) Inlet	Exit	Average Removal Efficiency (%)
IRON & STEEL INDUSTRY					
Gray Iron Cupola	Iron, Coke, Silica Dust	1-10	1-2	.05-.15	95
Oxygen Steel Converter	Iron Oxide	5-2	8-10	.05-.08	98.5
Steel Open Hearth Furnace (Scrap)	Iron & Zinc Oxide	.08-1	.5-1.5	.03-.06	95
Steel Open Hearth Furnace (Oxygen Lanced)	Iron Oxide	5-7	1-6	.01-.07	99
Blast Furnace (Iron)	Iron Ore & Coke Dust	.5-20	3-24	.008-.05	99
Electric Furnace	Ferro-Manganese Fume	.1-1	10-12	.04-.08	99
Electric Furnace	Ferro-Silicon Dust	.1-1	1-5	.1-.3	92
Rotary Kiln—Iron Reduction	Iron, Carbon	.5-50	3-10	.1-.3	99
Crushing & Screening	Taconite Iron Ore Dust	.5-100	5-25	.005-.01	99.9
CHEMICAL INDUSTRY					
Acid—Humidified SO_3	H_2SO_4 Mist				
(a) Scrub with Water		—	303*	1.7*	99.4
(b) Scrub with 40% Acid		—	406*	2.8*	99.3
Acid Concentrator	H_2SO_4 Mist	—	136*	3.3*	97.5
Copperas Roasting Kiln	H_2SO_4 Mist	—	198*	2.0*	99
Chlorosulfonic Acid Plant	H_2SO_4 Mist	—	756*	7.8*	98.9
Dry Ice Plant	Amine Fog	—	25*	2.0*	90+
Wood Distillation Plant	Tar & Acetic Acid	—	1080*	58.0*	95
$TiCl_4$ Plant, TiO_2 Dryer	TiO_2-HCl Fumes	.5-1	1-5	.05-.1	95
Spray Dryers	Detergents, Fume & Odor	—	—	—	95
Flash Dryer	Furfural Dust	.1-1	1-1.5	.05-.08	95+
Phosphoric Acid Plant	H_3PO_4 Mist	—	192*	3.8*	98+
NON-FERROUS METALS INDUSTRY					
Blast Furnace (Sec. Lead)	Lead Compounds	.1-1	2-6	.05-.15	99
Reverberatory Lead Furnace	Lead & Tin Compounds	.1-.8	1-2	.12	91
Ajax Furnace—Aluminum Alloy	Aluminum Chloride	.1-.9	3-5	.02-.05	95
Zinc Sintering	Zinc & Lead Oxide Dusts	.1-1	1-5	.05-.1	98
Reverberatory Brass Furnace	Zinc Oxide Fume	.05-.5	1-8	.1-.5	95
MINERAL PRODUCTS INDUSTRY					
Lime Kiln	Lime Dust	1-50	5-10	.05-.15	99+
Lime Kiln	Soda Fume	.3-1	2-5	.01-.05	98
Asphalt Stone Dryer	Limestone & Rock Dust	1-50	5-15	.05-.15	98+
Cement Kiln	Cement Dust	.5-55	1-2	.05-.1	97+
PETROLEUM INDUSTRY					
Catalytic Reformer	Catalyst Dust	.5-50	.09	.005	95+
Acid Concentrator	H_2SO_4 Mist	—	136*	3.3*	97.5
TCC Catalyst Regenerator	Oil Fumes	—	756*	8.0*	98+
FERTILIZER INDUSTRY					
Fertilizer Dryer	Ammonium Chloride Fumes	.05-1	.1-.5	.05	85+
Superphosphate Den & Mixer	Fluorine Compounds	—	300*	5.5*	98+
PULP & PAPER INDUSTRY					
Lime Kiln	Lime Dust	.1-50	5-10	.05-.15	99+
Lime Kiln	Soda Fume	.1-2	2-5	.01-.05	99
Black Liquor Recovery Boiler	Salt Cake	—	4-6	.4-.6	90
MISCELLANEOUS					
Pickling Tanks	HCl Fumes	—	25*	2.3*	90+
Boiler Flue Gas	Fly Ash	.1-3	1-2	.05-.08	98
Sodium Disposal Incinerator	Sodium Oxide Fumes	.3-1	.5-1	.02	98

* Milligrams per cubic ft

Note: The efficiencies shown above are average values for a particular plant or group of installations operating under a specific set of conditions.

*Figure 5.21 shows relationship of efficiency to pressure drop.

(SOURCE: OFFICE OF MANPOWER DEVELOPMENT, Reference 4)

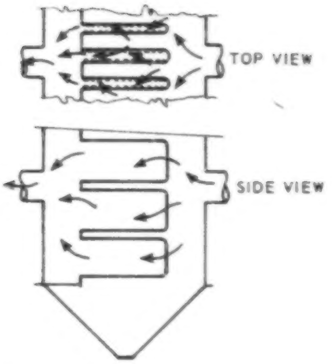

TOP VIEW
SIDE VIEW

Figure 5.26. TYPICAL FLAT OR ENVELOPE DUST COLLECTOR BAG (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

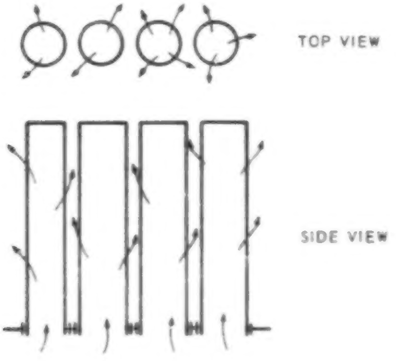

TOP VIEW
SIDE VIEW

Figure 5.27 TYPICAL ROUND OR TUBULAR DUST COLLECTOR BAG (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

gases may enter through the cleanout hopper in the bottom or through the top of the bags. (In the suction type [pullthrough] the dirty gases are forced through the inside of the bag and exit through the outside of the bag.) Figures 5.28 through 5.30 depict these flows. Other design variables are the type of fabric used (either woven for dust cake sieving or felted fabrics), bag cleaning mechanisms, equipment geometry and mode of operation.

Fabric filters are usually rated by the ratio of gas (CFM) to the area of the filter (square feet) which is the velocity of the gas through the filter cloth. A rule of thumb is a ratio of 1.5 to 3.0 CFM per square foot of cloth for dust and 1 to 2 CFM per square foot of cloth for fumes.

General operating characteristics of baghouses which the enforcement officer must understand are the following:

- The temperature and moisture content of the gases to be cleaned are important factors in the operation of baghouses. "Wet" gases will cause blinding (plugging) of the bags resulting in extremely high pressure drops which in turn will reduce the effectiveness of the entire collection system by reducing the volume of gases handled. The baghouse therefore should operate at a temperature above the dewpoint of the incoming gas. The closed suction type baghouse is used for gases with dewpoints between 165°F and 180°F. In this design, blower maintenance is less because it sees only clean gases. Open pressure type baghouses can handle hotter gases; however, this design will cause excessive wear on the fan, since it will handle the entire dust load.

- Physical shape and structural design are important to assure properly proportioned air flow through the bags, corrosion resistance and removal of the captured materials.

- Precooling equipment is a necessary part of most dust control systems using baghouses. Three cooling methods are usually employed:

  (a) Radiation and convection.

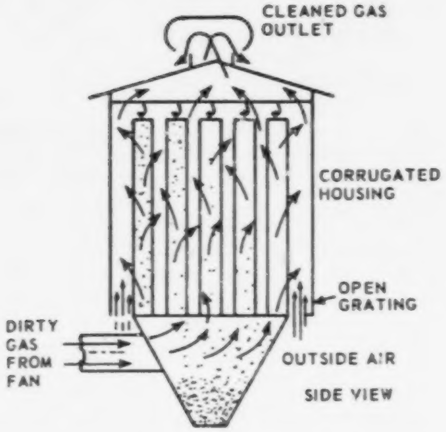
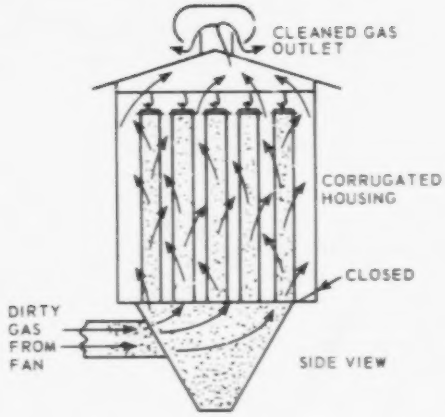

CLEANED GAS
OUTLET
CORRUGATED
HOUSING
OPEN
GRATING
DIRTY
GAS
FROM
FAN
OUTSIDE AIR
SIDE VIEW

Figure 5.28. OPEN PRESSURE BAGHOUSE


CLEANED GAS
OUTLET
CORRUGATED
HOUSING
CLOSED
DIRTY
GAS
FROM
FAN
SIDE VIEW

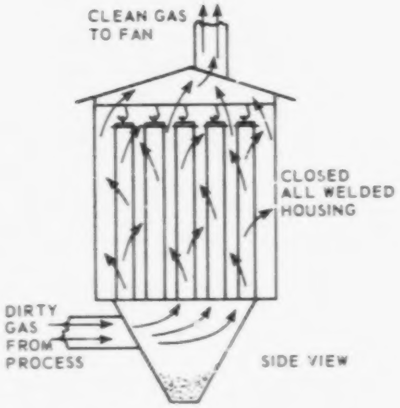

CLEAN GAS
TO FAN
CLOSED
ALL WELDED
HOUSING
DIRTY
GAS
FROM
PROCESS
SIDE VIEW

Figure 5.29. CLOSED PRESSURE BAGHOUSE Figure 5.30. CLOSED SUCTION BAGHOUSE

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

(b) Dilution air.

(c) Spray cooling.

- Radiation and convection cooling systems need large cooling surfaces resulting in considerable space requirements. A longer term penalty in additional motor horsepower needs will result from increasing the system pressure drop. Spray cooling is not advised for gases with high moisture content. Where dilution air is used, it is necessary to increase the filter area to comply with good practice thus making the installation costlier. Where spray cooling can be used, controls must be included to keep the temperature of the gases 50°F to 75°F above the dewpoint.(3)

- Bag cleaning techniques vary. Figures 5.31 through 5.39 describe the most common cleaning mechanisms. Bags may be mechanically shaken, fibrated by air jets or vibrated by sonic waves to remove the agglomerated dust and fumes on the cloth surface. The shaking reduces the pressure drop across the baghouse to ensure optimum resistance for high collection efficiency. It is therefore necessary that the enforcement officer become familiar with the various cleaning methods in common use.

- The properties of fabrics used and recommendations for operating temperatures, types of fabric vs. duct to be collected and filtering ratios are found in Tables 5.10 through 5.12. These are important guides to the enforcement officer. They assist him in determining whether or not the proper fabric is being used for any given application.

1. Inspection Points

a. Pressure Drop

Pressure drop across the baghouse can range from 0.5" W.G. to 8" W.G. The enforcement officer should determine from design information the operating range of the baghouse after shaking and when shaking is required. Many baghouses operate on a present time schedule, independent of pressure drop. In these cases there is a gas bypass system which is activated when the bags are to be cleaned.

b. Operation

The field enforcement officer should observe emissions during regular operations and during the cleaning cycle. The

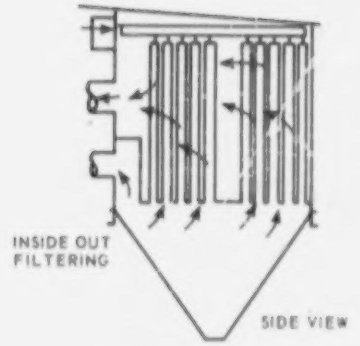

INSIDE OUT
FILTERING
SIDE VIEW

Figure 5.31. MECHANICAL SHAKING OF BOTTOM ENTRY DESIGN UNI-BAG DUST COLLECTOR.

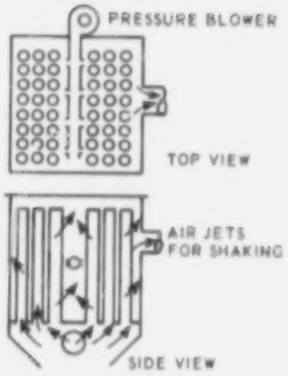

PRESSURE BLOWER
TOP VIEW
AIR JETS
FOR SHAKING
SIDE VIEW

Figure 5.32. AIR SHAKING WIND-WHIP CLEANS DUST COLLECTOR BAGS.

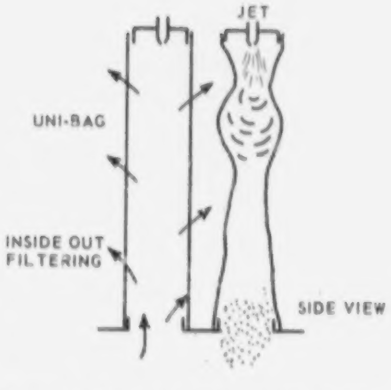

JET
UNI-BAG
INSIDE OUT
FILTERING
SIDE VIEW

Figure 5.33. BUBBLE CLEANING OF DUST COLLECTOR BAGS.

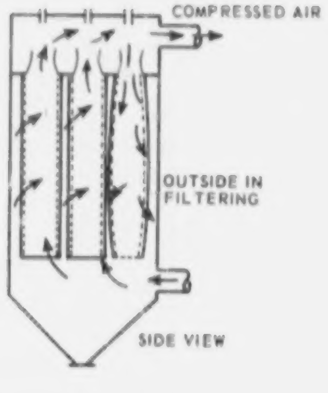

COMPRESSED AIR
OUTSIDE IN
FILTERING
SIDE VIEW

Figure 5.34. JET PULSE DUST COLLECTOR BAG CLEANING.

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

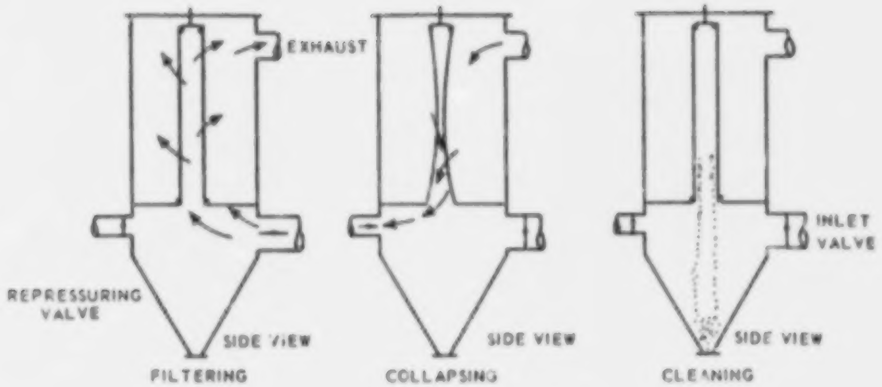

EXHAUST
INLET
VALVE
REPRESSURING
VALVE
SIDE VIEW
SIDE VIEW
SIDE VIEW
FILTERING
COLLAPSING
CLEANING

Figure 5.35. REVERSE AIR FLEXING TO CLEAN DUST COLLECTOR BAGS BY REPRESSURING.

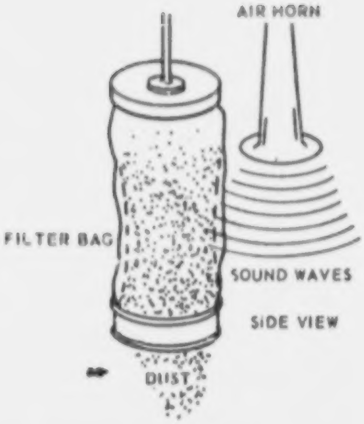

AIR HORN
FILTER BAG
SOUND WAVES
SIDE VIEW
DUST

Figure 5.36. SONIC CLEANING OF DUST COLLECTOR BAGS.

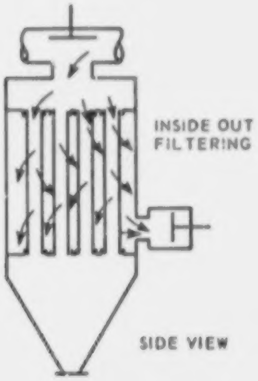

INSIDE OUT
FILTERING
SIDE VIEW

Figure 5.37. REPRESSURING CLEANING OF DUST COLLECTOR BAGS.

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

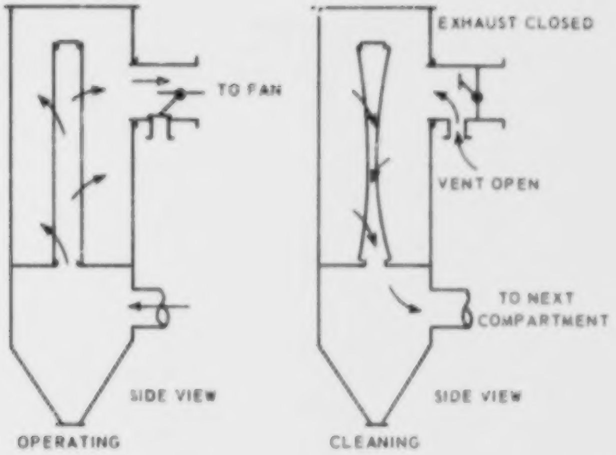

EXHAUST CLOSED
TO FAN
VENT OPEN
TO NEXT COMPARTMENT
SIDE VIEW
SIDE VIEW
OPERATING
CLEANING

Figure 5.38. CLOTH CLEANING BY REVERSE FLOW OF AMBIENT AIR.

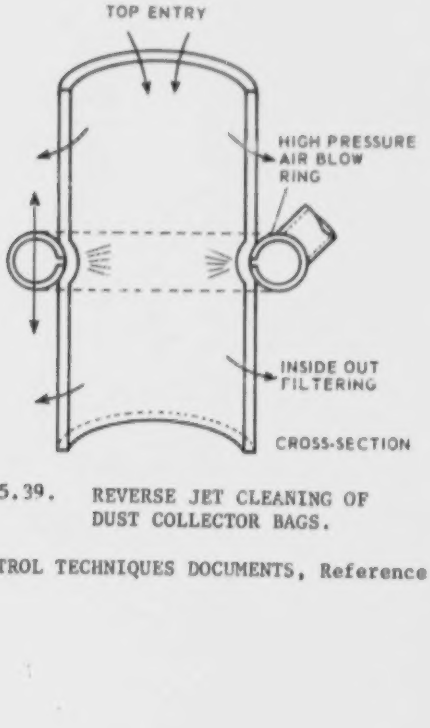

TOP ENTRY
HIGH PRESSURE AIR BLOW RING
INSIDE OUT FILTERING
CROSS-SECTION

Figure 5.39. REVERSE JET CLEANING OF DUST COLLECTOR BAGS.

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

Table 5.10. RECOMMENDED MAXIMUM FILTERING RATIOS AND DUST CONVEYING VELOCITIES FOR VARIOUS DUSTS AND FUMES IN CONVENTIONAL BAGHOUSES WITH WOVEN FABRICS.

Dust or fumes	Maximum filtering ratios, cfm/ft² cloth area	Branch pipe velocity, fpm
Abrasives	3.0	4500
Alumina	2.25	4500
Aluminum oxide	2.0	4500
Asbestos	2.75	3500–4000
Baking powder	2.25–2.50	4000–4500
Batch spouts for grains	3.0	4000
Bauxite	2.5	4500
Bronze powder	2.0	5000
Brunswick clay	2.25	4000–4500
Buffing wheel operations	3.0–3.25	3500–4000
Carbon	2.0	4000–4500
Cement crushing and grinding	1.5	4500
Cement kiln (wet process)	1.5	4000–4500
Ceramics	2.5	4000–4500
Charcoal	2.25	4500
Chocolate	2.25	4000
Chrome ore	2.5	5000
Clay	2.25	4000–4500
Cleanser	2.25	4000
Cocoa	2.25	4000
Coke	2.25	4000–4500
Conveying	2.5	4000
Cork	3.0	3000–3500
Cosmetics	2.0	4000
Cotton	3.5	3500
Feeds and grain	3.25	3500
Feldspar	2.5	4000–4500
Fertilizer (bagging)	2.4	4000
Fertilizer (cooler, dryer)	2.0	4500
Flint	2.5	4500
Flour	2.5	3500
Glass	2.5	4000–4500
Granite	2.5	4500
Graphite	2.0	4500
Grinding and separating	2.25	4000
Gypsum	2.5	4000
Iron ore	2.0	4500–5000
Iron oxide	2.0	4500
Lampblack	2.0	4500
Lead oxide	2.25	4500
Leather	3.5	3500
Lime	2.0	4000
Limestone	2.75	4500
Manganese	2.25	5000
Marble	3.0	4500
Mica	2.25	4000
Oyster shell	3.0	4500
Packing machines	2.75	4000
Paint pigments	2.0	4000
Paper	3.5	3500
Plastics	2.5	4500
Quartz	2.75	4500
Rock	3.25	4500
Sanding Machines	3.25	4500
Silica	2.75	4500
Soap	2.25	3500
Soapstone	2.25	4000
Starch	2.25	3500
Sugar	2.25	4000
Talc	2.25	4000
Tobacco	3.5	3500
Wood	3.5	3500

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

Table 5.11. RECOMMENDED MAXIMUM FILTERING RATIOS AND FABRIC FOR DUST AND FUME COLLECTION IN REVERSE-JET BAGHOUSES.

Material or operation	Fabric	Filtering ratios, cfm/ft^2
Aluminum oxide	Napped cotton	11
Bauxite	Cotton sateen	10
Carbon, calcined	Napped cotton, wool felt.	8 [a]
Carbon, green	Orlon felt	7
Carbon, banbury mixer.	Wool felt	8
Cement, raw	Cotton sateen	9
Cement, finished	Cotton sateen	10
Cement, milling	Cotton sateen	8
Chrome, (ferro) crushing.	Cotton sateen	10
Clay, green	Cotton sateen	10
Clay, vitrified silicious.	Cotton sateen	12
Enamel, (porcelain)	Napped cotton	12
Flour	Cotton sateen	14 [a]
Grain	Wool felt, cotton sateen.	16
Graphite	Wool felt	7 [a]
Gypsum	Cotton sateen, orlon felt.	10
Lead oxide fume	Orlon felt, wool felt.	8 [a]
Lime	Napped cotton	10
Limestone (crushing)	Cotton sateen	10
Metallurgical fumes	Orlon felt, wool felt.	10 [a]
Mica	Napped cotton	11
Paint pigments	Cotton sateen	10
Phenolic molding powders.	Cotton sateen	10
Polyvinyl chloride (PVC).	Wool felt	10 [a]
Refractory brick sizing (after firing).	Napped cotton	12
Sandblasting	Napped cotton, wool felt.	6-8 [a]
Silicon carbide	Cotton sateen	9-11
Soap and detergent powder.	Dacron felt, orlon felt.	12 [a]
Soy bean	Cotton sateen	14
Starch	Cotton sateen	10
Sugar	Cotton sateen, wool felt.	10 [a]
Talc	Cotton sateen	11
Tantalum fluoride	Orlon felt	6 [a]
Tobacco	Cotton sateen	12
Wood flour	Cotton sateen	10
Wood sawing operations.	Cotton sateen	12
Zinc, metallic	Orlon felt, dacron felt.	11
Zinc oxide	Orlon felt	8 [a]
Zirconium oxide	Orlon felt	8

[a] Decrease 1 cfm/ft^2 if dust concentration is high or particle size is small.

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

Table 5.12. FILTER FABRIC CHARACTERISTICS

Fiber	Operating exposure °F.		Supports com-bustion	Air perme-ability [a] cfm/ft^2	Composition	Resistance [b]				
	Long	Short				Abrasion	Mineral acids	Organic acids	Alkali	Cost [c] rank
Cotton	180	225	yes	10-20	Cellulose	G	P	G	G	1
Wool	200	250	no	20-60	Protein	G	F	F	P	7
Nylon [d]	200	250	yes	15-30	Polyamide	E	P	F	G	2
Orlon [d]	240	275	yes	20-45	Polyacrylonitrile	G	G	G	F	3
Dacron [d]	275	325	yes	10-60	Polyester	E	G	G	G	4
Polypropylene	200	250	yes	7-30	Olefin	E	E	E	E	6
Nomex [d]	425	500	no	25-54	Polyamide	E	F	E	G	8
Fiberglass	550	600	yes	10-70	Glass	P-F	E	E	P	5
Teflon [d]	450	500	no	15-65	Polyfluorcethylene	F	E	E	E	9

[a] cfm/ft^2 at 0.5 in. W.G.

[b] P = Poor, F = Fair, G = Good, E = Excellent.

[c] Cost rank, 1 = lowest cost, 9 = highest cost.

[d] Dupont registered trademark.

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

observation during bag shaking (Figure 5.40) may detect a time and opacity violation. In baghouses using reverse jet action, cleaning is continuous, allowing much higher air-to-cloth ratios. Some designs employ an air actuated ring which rides along the vertical axis of the bag. In this instance, the enforcement officer must also become familiar with the operation of the system to be certain that the cleaning mechanism is operating properly and not binding at any point.

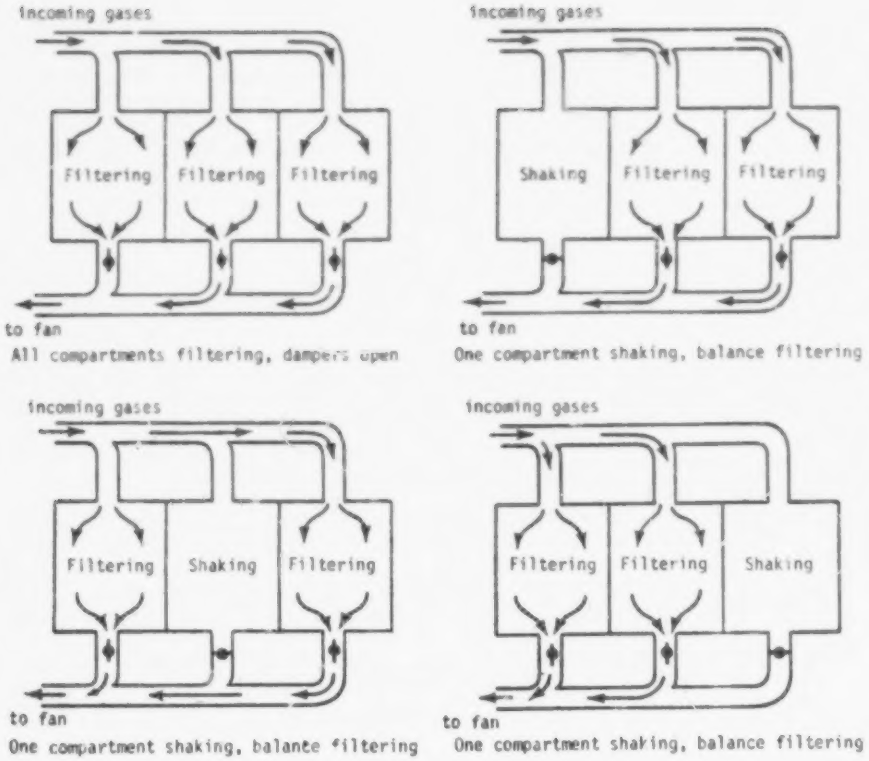
As a general rule, it is often necessary to know the maintenance schedule for closed baghouses in order to be able to inspect the inside of the equipment when it is offstream.

c. Maintenance

It is always necessary to consider the entire system and not only the air cleaning device. The enforcement officer, therefore, must determine the state of repair and operation of the hooding, ductwork, gas cooling equipment and fan, as well as the baghouse. Maintenance of the system is vital to its operation in order to avoid reduction in dust and fume pickup at the basic equipment caused by leaks in the system, fan deterioration due to handling high grain loading in a pressure system, or corrosion.

In systems where the material collected can be returned to the process or sold, the maintenance effort will more than likely be satisfactory. Where the material collected poses the additional problem of disposal, the enforcement officer should know what means are used to dispose of the collected material. Dumping the finely divided particulates onto the ground can result in a fugitive dust problem. In this regard, it is necessary to make sure that the collection hoppers are emptied on a regular basis and that the material is disposed of in a manner that will create the least problem, i.e., closed barrals, carts, trucks, etc.

A schedule of bag inspection leading to repair or replacement should be made available to the enforcement officer. This will be a very important tool in the determination of problems relating to baghouse system malfunctions. A well-defined program for bag replacement based upon expected baglife for the particular fabric used will help insure proper operation and minimal downtime (see Table 5.13).


incoming gases
Filtering
Filtering
Filtering
to fan
incoming gases
Shaking
Filtering
Filtering
to fan
incoming gases
Filtering
Shaking
Filtering
to fan
incoming gases
Filtering
Filtering
Shaking
to fan

All compartments filtering, dampers open

One compartment shaking, balance filtering

One compartment shaking, balante filtering

One compartment shaking, balance filtering

Figure 5.40. TYPICAL PARALLEL FLOW SYSTEM FOR A CONVENTIONAL MULTICOMPARTMENT BAGHOUSE (SOURCE: OFFICE OF MANPOWER DEVELOPMENT, Reference 4)

Table 5.13. TROUBLESHOOTING CHECKLIST FOR FABRIC FILTERS*

"Condition: High differential pressure (Note: Most installations are designed for differential pressure of 3 to 4 in. A differential pressure of 1 in. to 6 in. can be considered normal).

1. Improper compressed air supply (80 to 100 psig is required. More effective cleaning is possible with pressures up to 110 psig).

2. Improper timer operation. Make sure all valves are being activated. Check for sticking timer relay.

3. Improper solenoid valve operation. A leaking diaphragm will reduce cleaning energy by slowing or preventing valve opening.

4. Leaky airlock or dust discharge valve can overload collector by preventing dust discharge.

5. Moisture blinded bags. Recovery is often possible by running the cleaning mechanism without moving air through the collector from one to 30 hours.

6. Considerable dust in the clean air plenum (from a previously leaky bag, etc) can reduce cleaning effectiveness by impregnating the bags in the reverse direction.

7. Static electricity can cause a high differential pressure. Increase humidity if possible.

8. Make sure blow tubes are installed correctly (field assembly units).

9. Collector overloaded by too much air. Check fan speed. Check damper adjustment and system design.

"Condition: Seepage - Visible discharge
Points to check and remedy:

1. Improperly installed bags.
2. Loose bag clamps.
3. Torn bags or holes in bags.
4. Improper sealing of tube sheet joints (field assembled units).
5. Missing or loose venturi rivets.

---

* Primarily for pulse cleaned equipment; from Mikro-pulsaire Instruction Manual, Pulverizing Machinery Corp.

(SOURCE: APPENDIX OF HANDBOOK OF FABRIC FILTER TECHNOLOGY, Reference 9.)

Table 5.13. TROUBLESHOOTING CHECKLIST FOR FABRIC FILTERS (continued)

"Condition: Insufficient suction on exhaust hood or system
Points to check and remedy:

1. Fan direction of rotation incorrect. Fan will pump air inefficiently if wrong direction.

2. Check for high differential pressure (see above

3. Slippage on fan belts?

4. Leaking duct work? Access doors? Explosion doors? Discharge valve on air lock?

5. Clogged duct, or closed gate, or damper.

6. Duct size or run other than original design.

7. Poor system design?

"Condition: Unable to maintain compressed air pressure
Points to check and remedy:

1. Dirty solenoid valve sticking open. Clean and check pilot plunger.

2. Short circuit in wiring keeping one or more valves open.

3. Sticking timer relay, or pulse longer than 0.15 seconds.

4. Faulty or too small a compressor, and/or pipe leaks.

5. Solenoid valves require a minimum of 5 psig to close. A long compressed air run after the shut-off valve can prevent the required 5 psig from developing. Solution to this would be provision of reservoir and shut-off valve near the collector.

"Condition: Filter cylinder problems (blinding, poor life, etc.)
Points to check and remedy:

1. Check operating temperature (e.g. 180 deg. for wool).

2. Check operating humidity, free moisture, etc. (relative humidity is too low if static electricity occurs).

3. Check for shrinkage, free moisture, etc.

Table 5.13. TROUBLESHOOTING CHECKLIST FOR FABRIC FILTERS (continued)

4. Review physical and chemical characteristics of material and gas stream.

5. Check for hopper bridging. Material buildup into the bag area can overstress elements.

6. Incorrect bag retainer installation can cause bag wear by allowing friction between adjacent elements or between outside elements and housing. Make sure tubes are installed vertically."

d. Temperature and Dew Point

The enforcement officer must determine the nominal operating conditions for baghouses. Good operating procedures dictate that the gas temperature should be 50°F to 75°F above the dew point. This temperature will then determine the fabric to be used for the given operating condition. Table 5.12 will be helpful in making this determination. In baghouses using reverse jet action for cleaning, the compressed air used to blow the dust from the inside of the bag may have to be heated to avoid blinding the bags from condensed moisture. In some baghouses, it may be necessary to maintain the temperature significantly above ambient by the use of heaters when it is down, to preclude blinding from moisture at startup.

e. General

Mechanical devices need to be tended and maintained, including painting to retard corrosion and lubrication of moving parts and repairs. Mechanical shakers, screw conveyors and other materials handling equipment must be kept in good working order to prevent equipment downtime.

F. Electrostatic Precipitators

Electrostatic precipitators employ the principle of attraction of opposite charges. The particles in the contaminated exhaust stream are charged in a high voltage electric field and are then attracted to a plate of the opposite charge where they are collected. When the plate is shaken or rapped, the contaminants drop into a hopper.

There are 2 basic types of electrostatic precipitators. Single-stage precipitators operating at high voltage, 30 to 100 KV peak voltage, and 2-stage, low-voltage precipitators operating at 12 to 13 KV. The higher voltage precipitator is commonly used in large installations such as coal-burning central power stations and Portland cement plants. The low-voltage, 2-stage precipitators are used to control mists and other particulates from smokehouses, asphalt paper saturators, pipe-coating machines and high-speed grinders.(3)

1. High Voltage Precipitators

High voltage precipitators operate in four basic steps:(4)

- Electrically charging the particles to be collected from the gas stream by ionization.
- Transporting the charged particles by means of the force exerted upon them by the electric field to a collecting surface.
- Neutralizing the electrically charged particle precipitated on the collecting surface.
- Removing the precipitated particles from the collecting surface.

There are 2 designs of the 1-stage precipitator in general use which combines ionization and collection in a single stage. They are:

- Wire-in-plate (Figure 5.41)
- Wire-in-tube (Figure 5.42).

The wire-in-plate design uses grounded parallel plates 6 to 12 inches apart with the wire equidistant between the plates (Figure 5.43). The wire-in-tube design uses cylinders as grounded collectors with the wire suspended on the centerline of the tube (Figures 5.42 and 5.44). The high voltage current is provided by transformers (usually oil cooled) with rectifiers for converting the alternating current to direct current.

After the charged particles have been collected on the plates or tubes, effective removal is the next step in the operation. Liquid particulates flow down the grounded collector to the bin by gravity. Solid particulates must be dislodged by mechanical

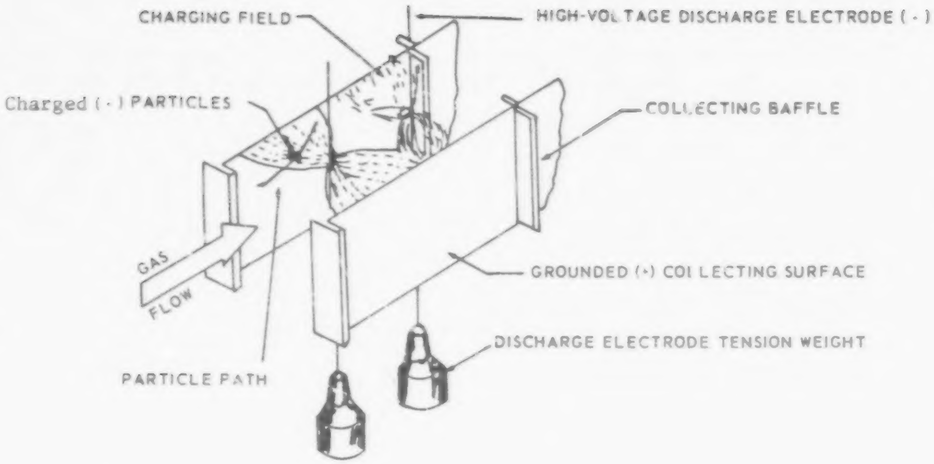

CHARGING FIELD
HIGH-VOLTAGE DISCHARGE ELECTRODE (-)
Charged (-) PARTICLES
COLLECTING BAFFLE
GAS FLOW
GROUNDED (+) COLLECTING SURFACE
DISCHARGE ELECTRODE TENSION WEIGHT
PARTICLE PATH

Figure 5.41. SCHEMATIC VIEW OF A FLAT SURFACE-TYPE ELECTROSTATIC PRECIPITATOR (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

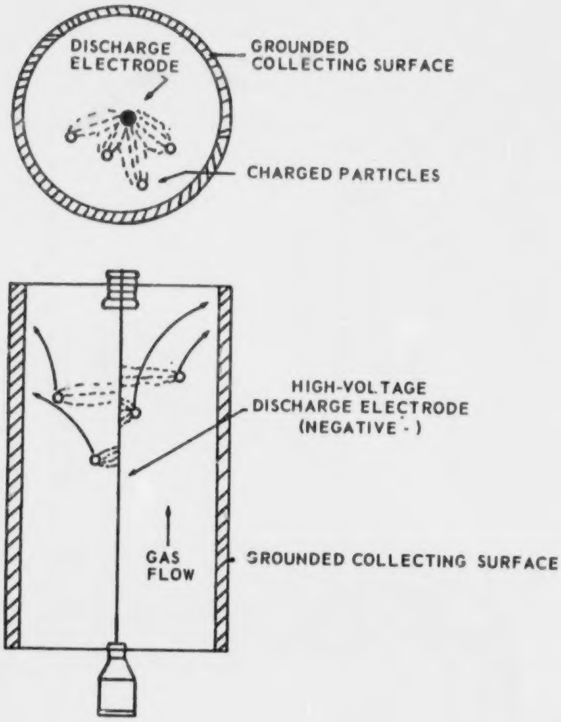

DISCHARGE ELECTRODE
GROUNDED COLLECTING SURFACE
CHARGED PARTICLES
HIGH-VOLTAGE DISCHARGE ELECTRODE (NEGATIVE -)
GAS FLOW
GROUNDED COLLECTING SURFACE

Figure 5.42. SCHEMATIC VIEW OF TUBULAR SURFACE-TYPE ELECTROSTATIC PRECIPITATOR (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

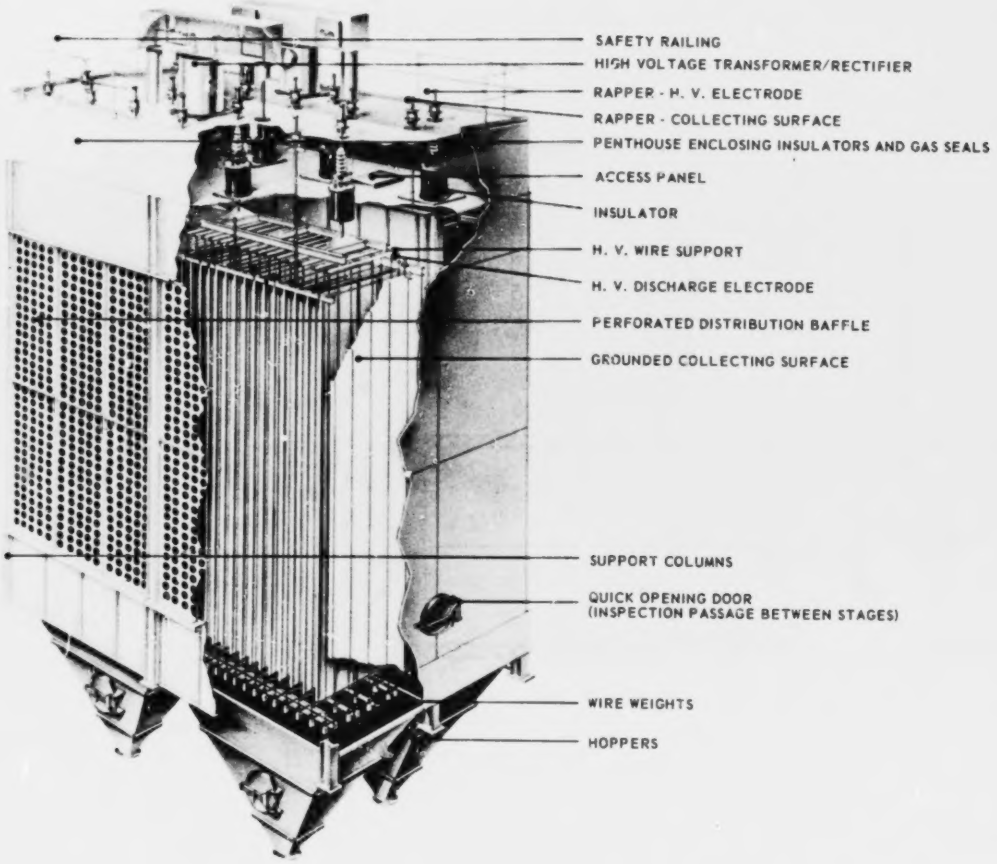

SAFETY RAILING
HIGH VOLTAGE TRANSFORMER/RECTIFIER
RAPPER - H. V. ELECTRODE
RAPPER - COLLECTING SURFACE
PENTHOUSE ENCLOSING INSULATORS AND GAS SEALS
ACCESS PANEL
INSULATOR
H. V. WIRE SUPPORT
H. V. DISCHARGE ELECTRODE
PERFORATED DISTRIBUTION BAFFLE
GROUNDED COLLECTING SURFACE
SUPPORT COLUMNS
QUICK OPENING DOOR
(INSPECTION PASSAGE BETWEEN STAGES)
WIRE WEIGHTS
HOPPERS

Figure 5.43. CUTAWAY VIEW OF A FLAT SURFACE-TYPE ELECTROSTATIC PRECIPITATOR (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

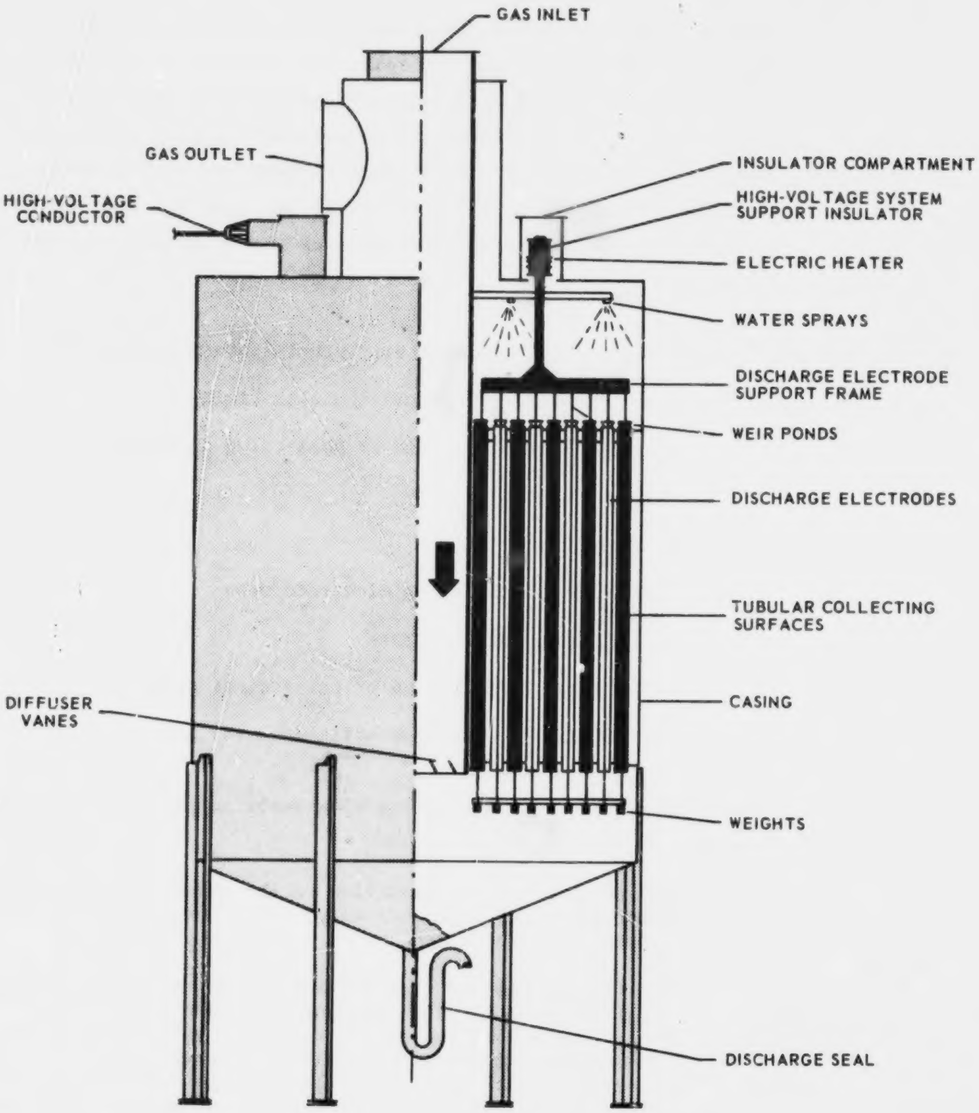

GAS INLET
GAS OUTLET
HIGH-VOLTAGE CONDUCTOR
INSULATOR COMPARTMENT
HIGH-VOLTAGE SYSTEM SUPPORT INSULATOR
ELECTRIC HEATER
WATER SPRAYS
DISCHARGE ELECTRODE SUPPORT FRAME
WEIR PONDS
DISCHARGE ELECTRODES
TUBULAR COLLECTING SURFACES
CASING
DIFFUSER VANES
WEIGHTS
DISCHARGE SEAL

Figure 5.44. CROSS-SECTIONAL VIEW OF IRRIGATED TUBULAR BLAST FURNACE PRECIPITATOR (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

means such as rapping or vibration. Collection of the solid particles and removal from the collection hoppers is a design problem usually solved by using screw or pneumatic conveyors. Hopper bottoms can be fitted with swing valves, slide gates or rotary vane type valves. Some precipitators use a water spray to clean the plates which may result in the need for drag chains or other devices to preclude bridging of the collected material in the hoppers.

Design parameters for electrostatic precipitators include:(4)

- Peak effective electrical charging field.
- Average electrical field at collecting electrode.
- Particle radius
- Gas velocity
- Precipitator collecting electrode area
- Precipitator gas flow rate
- Efficiency of collection of particulate size.

Figure 5.45 indicates collection efficiency vs. particle size.

Practical aspects of high voltage electrostatic precipitator design include:

- Modification of the condition of the gases upstream of the precipitator to cool, humidify, dilute or introduce additives to the gases.
- Sectionalization of single-stage precipitators is usually required since large volumes of gases are handled and conditions within the precipitator may vary requiring adjustments in current and voltage to compensate for the variation. Each section should have its own power controls and supply to ensure peak efficiency and to prevent power fluctuations. Power controls regulate current, voltage and sparking.

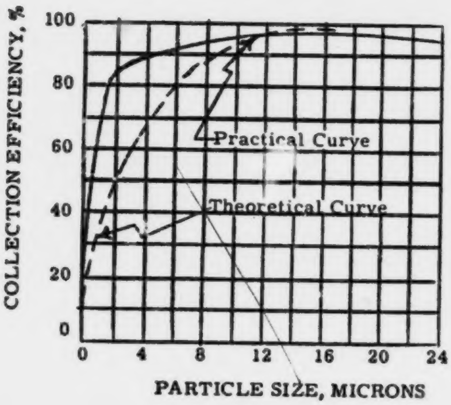


Figure 5.45. SIZE-EFFICIENCY CURVES FOR ELECTROSTATIC PRECIPITATOR (SOURCE: OFFICE OF MANPOWER DEVELOPMENT, Reference 4)

- Sparking control is necessary because in some designs sparking is desirable to obtain optimum collection efficiency.(5) Other designs dictate no sparking. Optimum sparking is dependent upon such factors as precipitator size, fume characteristics and fume concentration. Figure 5.46 illustrates this point.

- Gas velocity, treatment time in the precipitator and flow distribution are vital factors in the collection efficiency of precipitators. Uniform gas velocity through all sections of the precipitator is the optimum case. Velocities range from 3 to 15 feet per second. Table 5.14 shows values used by precipitator manufacturers gained through years of experience in the field.

- Electrical resistivity is the resistance of certain particles to maintaining a negative charge which negates the attraction of the positively charged collector. The resistivity varies with temperature and moisture content. Figure 5.47 illustrates this point. These deficiencies are overcome by the addition of water vapor, acid or other conducting material to increase the surface conductivity of highly resistive particulates.(5)

  Conditioning agents include:

  (1) Ammonia.

  (2) Triethylamine for acid particles not readily wetted with moisture.

  (3) Acid salts, sulfuric acid and SO_3 for basic particles. The SO_3 that may be found in stacks carrying cool combustion effluents may be an aid in precipitating fly ash.

In addition to observing the precipitator discharge, the enforcement officer must learn the operating limits for good collection as indicated by the following:

- Individual (sectional) electrical set controls and instruments.

- Spark rate indicators.

- Rapping, cycle, frequency, intensity and duration controls and indicators.

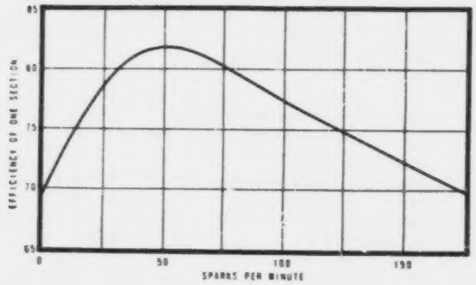


Figure 5.46. VARIATION OF PRECIPITATOR EFFICIENCY WITH SPARKING RATE FOR A REPRESENTATIVE FLY-ASH PRECIPITATOR, WHITE, 1953 (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

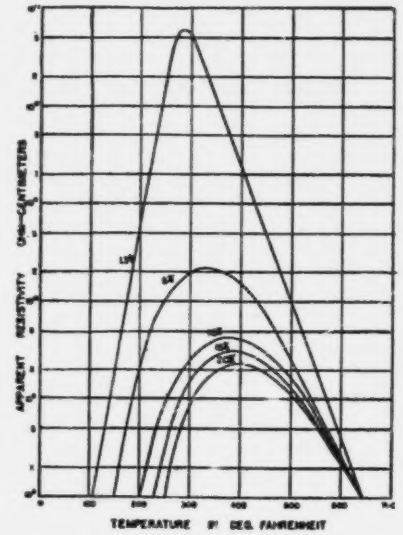


Figure 5.47. EFFECT OF MOISTURE CONTENT ON APPARENT RESISTIVITY OF PRECIPITATED CEMENT DUST (SOURCE: OFFICE OF MANPOWER DEVELOPMENT, Reference 4)

Table 5.14. TYPICAL VALUES OF SOME DESIGN VARIABLES USED IN COMMERCIAL ELECTRICAL PRECIPITATOR PRACTICE.

Design variable	Normal range of values
Plate spacing	8 to 11 in.
Velocity through precipitator	2 to 8 ft/sec
Vertical height of plates	12 to 24 ft
Horizontal length of plates	0.5 to 1.0 x height
Applied voltage	30 to 75 kv
Drift velocity w	0.1 to 0.7 ft/sec
Gas temperature	up to 700°F standard 1,000°F high temperature 1,300°F special
Treatment time	2 to 10 sec
Draft loss	0.1 to 0.5 in. WC
Efficiency	up to 99.9+% usually 90% to 98%
Corona current	0.01 to 1.0 ma/ft wire
Field strength	7 to 15 kv/in.

(SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

- Outlet opacity indicators.
- Line voltage indicators.

a. Inspection Points

The enforcement officer must determine from the operator of the equipment the design characteristics which may be checked during operation from the instruments and controls cited above. These include:

- Power supply
  - (1) Direct current at potential close to that required for arcing.
  - (2) Input source of power.
  - (3) Regulation of voltage during arcing.
  - (4) Output power:
    - (a) Voltage 30 to 100 KV.
    - (b) Current 20 to 100 MA.

  (The use of automatic voltage controls will result in increased collection efficiency.)

- Operation - general
  - (1) Changes in particulate loading.
    - (a) Process changes.
    - (b) Raw material change.
    - (c) Fuel rate or grade change.
    - (d) Gas stream conditioning change.
  - (2) Alarms for signaling control variable deviation.
  - (3) Malfunction of control valves, gates or conveyors.
  - (4) Mechanical maintenance of conveyors, required to prevent corrosion, etc.

- Operation of wet precipitators.
  - (1) Collection of grease on the inside of tube electrodes.
  - (2) Check water sprayed for mineral content to reduce deposition of solids.
  - (3) Recirculated water should be treated for removal of solids.

- Operation of dry-type precipitators
  (1) Prevention of re-entrainment of dust in the gas stream.
  (2) Rapping mechanism must operate properly, i.e., proper maintenance is required. Some types are:
    (a) Mechanical.
    (b) Compressed air actuated.
    (c) Magnetic impulse actuated.
  (3) Some particulates require the application of an adhesive to the collection electrodes. This can be removed only by washing. After washing is complete, the adhesive must be reapplied. Extensive problems can be caused if a rigid cleaning schedule is not followed.

2. Two-Stage Precipitators

Low-voltage, 2-stage electrostatic precipitators have come into use to control emissions from operations "smaller" than cement kilns or coal-fired power plants and for particulate removal from air conditioning systems. Their effectiveness falls off rapidly if the grain loading of the inlet gases exceeds 0.4 grains per standard cubic feet or if the material to be collected is solid or sticky.(4) Thus the equipment is recommended only with low grain loading.

The two stages of the equipment are:

a. Ionization, which is accomplished by a series of fine wires 1 to 2 inches apart, positively charged, placed parallel to grounded tubes (Figure 5.48). There is a high voltage corona discharge which ionizes gas molecules that cause charging of particles passing through the field. The direct current potential applied to the wires is 12 to 13 KV.

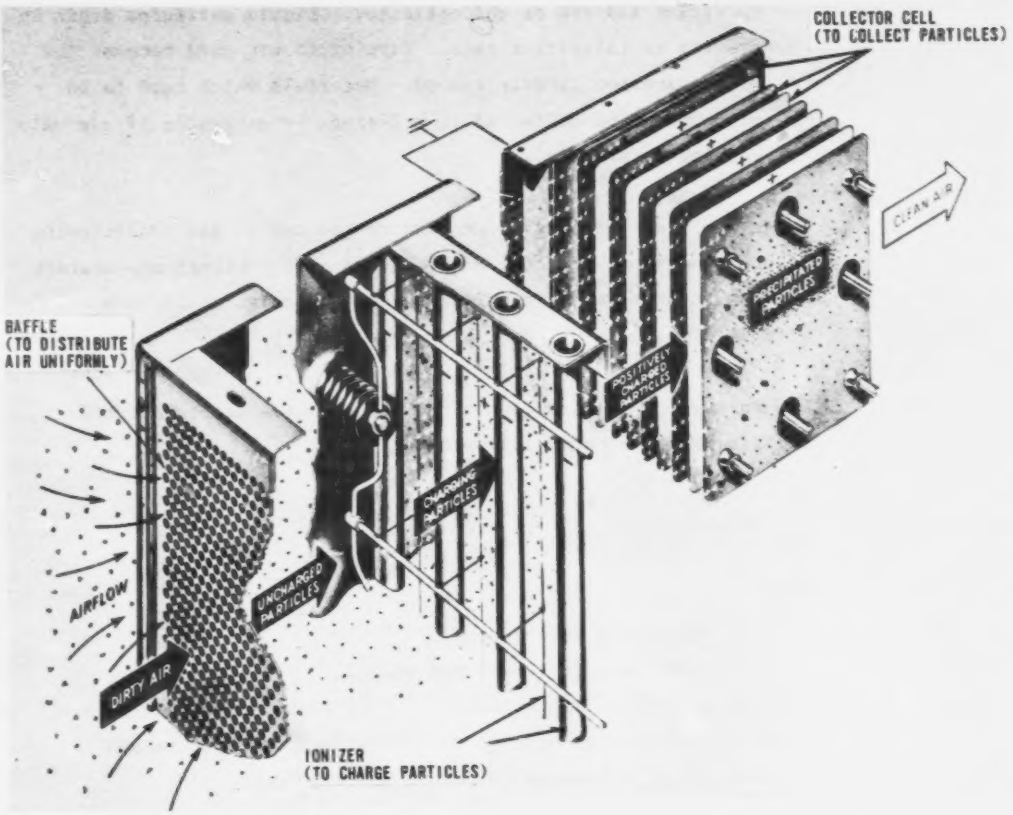

COLLECTOR CELL
(TO COLLECT PARTICLES)
CLEAN AIR
PRECIPITATED PARTICLES
POSITIVELY CHARGED PARTICLES
CHARGING PARTICLES
BAFFLE
(TO DISTRIBUTE
AIR UNIFORMLY)
UNCHARGED PARTICLES
AIRFLOW
DIRTY AIR
IONIZER
(TO CHARGE PARTICLES)

Figure 5.48. COMPONENTS OF STANDARD TWO-STAGE PRECIPITATOR, WESTINGHOUSE ELECTRIC CORPORATION, HYDE PARK, BOSTON, MASSACHUSETTS (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

b. The second stage is a series of grounded plates usually less than 1 inch apart which attract the positively charged particles and act as the collector. Liquid particles drain by gravity to collection pans. Rapping is not used because the plates are too closely spaced. Materials which tend to be viscous can be collected in a 2-stage precipitator if adequate washing is provided.

Two-stage precipitators often require the use of gas conditioning or precleaning equipment. Mist eliminators, precleaners, heaters and humidifiers may be required to attain design collection efficiencies.

Low-voltage, 2-stage precipitator efficiencies are calculated according to the Penny (1937) equation:

$$F = \frac{wL}{vd}$$

where

F = efficiency as a decimal
w = drift velocity, feet per second
L = collector length, feet
v = gas velocity through the collector, feet per second
d = distance between collector plates, feet.

In air-conditioning applications of the 2-stage precipitator, the dust grain loading is lighter so that the velocity range is from 5 to 10 feet per second. Heavier grain loading in air pollution control applications for this type of precipitator requires reduced velocities on the order of 1.7 feet per second.

c. Inspection Points

The inspection points for 2-stage precipitators are the same as those described for single-stage precipitators. The enforcement officer should know the maintenance schedule since this is the only way that the collected material will be removed from the plates (unless oils are collected which will run off the plates). The maintenance schedule can be from 1 to 6 weeks depending on the material collected in the precipitator. During this period, the ionizing wires should also be inspected for corrosion damage to determine replacement requirements.

3. Maintenance

Schedules should be established to inspect, service and repair critical precipitator components. Table 5.15 shows a typical maintenance schedule for a fly ash precipitator.(10) The major components are rappers, transformers, electrodes, particulate removal equipment and electrical controls.

VI. SULFUR DIOXIDE REMOVAL SYSTEMS FOR POWER PLANTS

The removal of SO_2 from the exhaust gases of power plants remains a major air pollution control problem. Extensive research and development work is in progress to determine effective and economical processes for SO_2 removal. The processes now in use which reflect the state-of-the-art are limestone-dolomite injection (wet and dry) and catalytic oxidation. In addition to these processes limits on the sulfur content of fuels are also a significant step towards the reduction of SO_2 from power plants.

A. Limestone/Dolomite Injection-Dry Process(3)

Pulverized limestone or dolomite is injected into the combustion zone of large steam generators where it is calcined into lime. The lime

Table 5.15. TYPICAL MAINTENANCE SCHEDULE FOR ELECTROSTATIC PRECIPITATORS

A. Annual Inspection

1. Internal inspection

    a. Observe dust deposits on collecting plates and wire before cleaning - a ¼" deposit is normal. If metal plates are clean, there is a possibility that a section is shorting out. If more than ¼" of dust is on plates, rappers are not cleaning.

    b. Observe dust buildup on wires.

    c. Interior corrosion - corrosion could indicate air leak through shell, or could indicate moisture carryover from air heater washer.

    d. Plate corrosion adjacent to door or near bottom of plate could indicate inleakage through doors.

    e. Check plates for alignment and equal spacing between plates.

    f. Measure to see that discharge wires hang midway between plates.

    g. Check for and replace broken wires.

2. Hopper inspection

    a. Check for dust buildup in upper corners of hoppers.

    b. Check anti-sway insulators to see that they are cleaned and not cracked.

    c. Check high tension weights - if one has dropped 3", this indicates broken wire.

    d. Check hopper bottom and valve for debris.

(SOURCE: Reference 10)

Table 5.15. TYPICAL MAINTENANCE SCHEDULE FOR ELECTROSTATIC PRECIPITATORS (continued)

3. Penthouse inspection
    a. Check for corrosion due to condensation and/or leakage of flue gas into housing.
    b. Excessive dust in penthouse indicates air sealing pressure too low.
    c. Clean all high tension insulators.
    d. Check that all high tension connections are secure.
    e. Check that collars on high tension vibrator insulators are secure.
4. Transformer inspection
    a. Check liquid level.
    b. Clean high tension line, insulators, bushings, and terminals.
    c. Check surge arrestors, spark gap should be $\frac{1}{32}$".
5. Control cabinet inspection
    a. Clean and dress relay contacts.

B. Rappers and Vibrators Checked Quarterly

1. Rappers
    a. Check distributor switch contacts for wear and lubricate.
    b. Clean dust, dirt, and moisture from cabinet.
    c. Check rapper assembly for binding at plunger or misalignment.

Table 5.15. TYPICAL MAINTENANCE SCHEDULE FOR ELECTROSTATIC PRECIPITATORS (continued)

2. Vibrators
    a. Check contacts on load cams to see that they are clean.
    b. Clean dirt, dust, and moisture from cabinet.
    c. Check vibrators to see that they operate at proper intervals.

C. Checks to Be Made Each Shift

1. Electrical reading for each control unit should be recorded and checked for abnormal readings.
2. Rapper controls should be checked to see that they operate.
3. Vibrator controls should be checked.

(SOURCE: OGLESBY, JR. ET AL, Reference 10) reacts with the oxides of sulfur from the combustion of the fuel (at temperatures over 1200°F) to form gypsum ($CaSO_4$). The sulfate particulates formed as a result of this reaction, unreacted lime and fly ash are then removed from the stack gases by an electrostatic precipitator, or combination of high efficiency mechanical collector and a precipitator. Figure 5.49 is a flow chart of a prototype system using lime/dolomite injection with "dry" collection. The efficiency range for removal of SO_2 by this process is 40-60 percent.(7)

B. Limestone/Dolomite Injection-Wet Process(4)

Ground limestone or dolomite is injected into the furnace combustion zone in a manner similar to the "dry" process. In the wet process, the boiler exhaust gases containing the particulates formed are scrubbed in a lime slurry. The lime slurry is recycled from a settling tank to the scrubber. Disposal of the sediment may be a problem if adequate facilities are not available. Figure 5.50 is a schematic drawing of a wet system. Collection efficiencies expected from the wet process range between 80-90 percent.

C. Catalytic Oxidation

Catalytic oxidation of SO_2 to SO_3 is a variation of the contact catalytic process used in the manufacture of sulfuric acid, described in Chapter 7, Section VII. As an air pollution control measure, the mechanism forms SO_3 from SO_2 by action of a vanadium pentoxide catalyst which then combines with the moisture in the products of combustion to form sulfuric acid. The gas thus treated must first be subjected to highly efficient particulate removal since very small amounts of selenium, arsenic or chlorides can deactivate the vanadium pentoxide catalyst. Figure 5.51 is a schematic drawing of this process. Collection efficiencies of 90 percent(7) should be expected from this system. The drawbacks to this system may overshadow its effectiveness. These are:

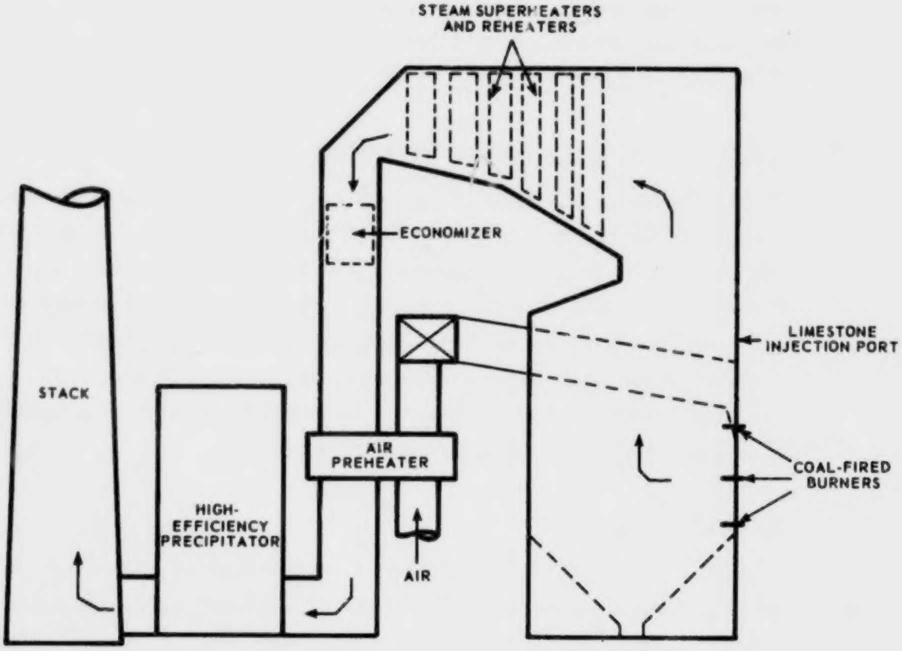

STEAM SUPERHEATERS AND REHEATERS
ECONOMIZER
LIMESTONE INJECTION PORT
STACK
AIR PREHEATER
COAL-FIRED BURNERS
HIGH-EFFICIENCY PRECIPITATOR
AIR

Figure 5.49. LIMESTONE INJECTION - DRY PROCESS (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

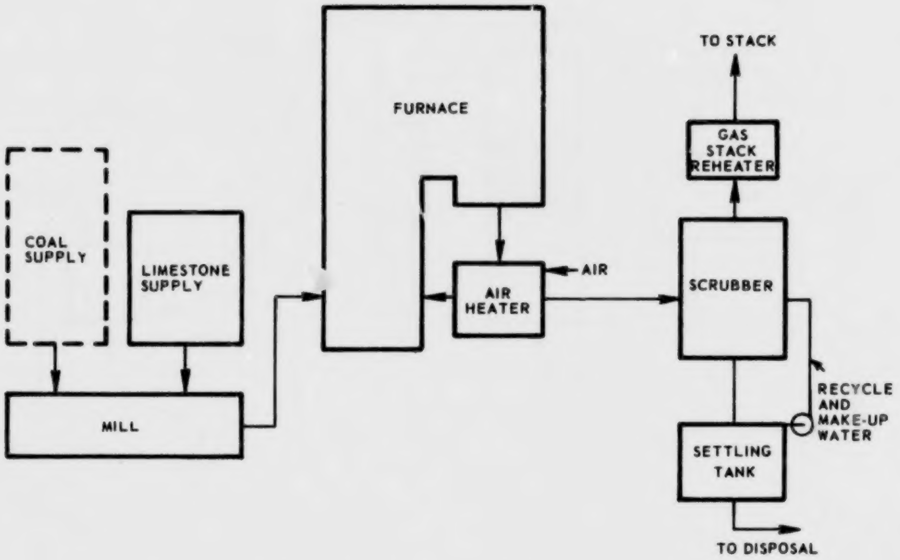

FURNACE
TO STACK
GAS STACK REHEATER
COAL SUPPLY
LIMESTONE SUPPLY
AIR
AIR HEATER
SCRUBBER
MILL
RECYCLE AND MAKE-UP WATER
SETTLING TANK
TO DISPOSAL

Figure 5.50. LIMESTONE INJECTION - WET SCRUBBING PROCESS (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

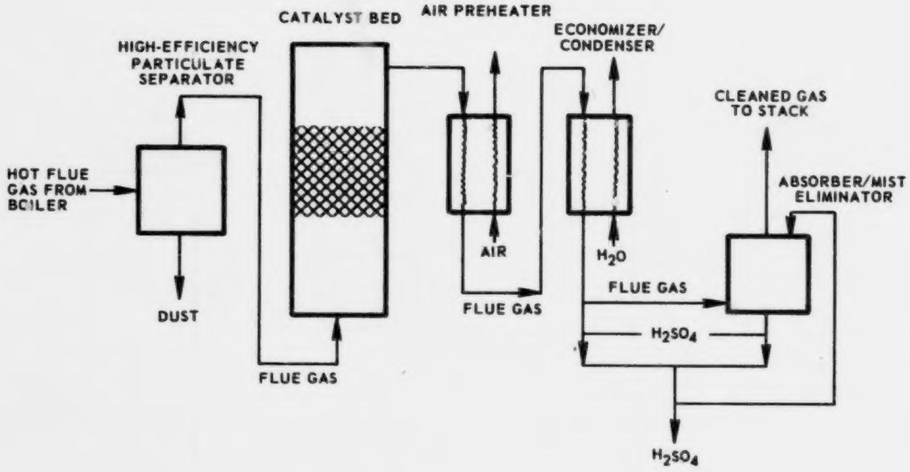

CATALYST BED
AIR PREHEATER
ECONOMIZER/ CONDENSER
HIGH-EFFICIENCY PARTICULATE SEPARATOR
CLEANED GAS TO STACK
HOT FLUE GAS FROM BOILER
ABSORBER/MIST ELIMINATOR
AIR
H_2O
DUST
FLUE GAS
FLUE GAS
FLUE GAS
H_2SO_4
FLUE GAS
H_2SO_4

Figure 5.51. CATALYTIC OXIDATION PROCESS (SOURCE: CONTROL TECHNIQUES DOCUMENTS, Reference 3)

- The requirement for the use of costly corrosion-resistant construction materials.
- Boiler redesign to supply the converter with high temperature (850°F) flue gas.
- Lack of a market for the 75-80 percent acid captured.

D. Inspection Points

1. Lime Injection, Dry and Wet Processes

In addition to the inspection points for boilers described in Chapter 7, the enforcement officer must determine the optimum rate of lime injection into the furnace. Maintenance of this rate is essential for the formation of the particulates which will be captured by the precipitator or scrubber. Inspection of the equipment and operation will provide a qualitative estimate of emissions but stack sampling is the only way that the actual effectiveness of the system can be determined.

2. Catalytic Oxidation Process

Before oxidation of SO_2 to SO_3 can take place as a result of flue gases going through the catalyst bed, the gases must be virtually free of particulates. This means that the enforcement officer must be sure that the dust collector upstream of the catalyst bed is operating properly. The enforcement officer should check for corrosion to make sure that the scrubber and mist eliminator are not damaged to the point where the effectiveness is reduced. Only stack testing will provide quantitative data regarding the effectiveness of the system.

VII. CONTROL EQUIPMENT FOR GASES AND VAPORS

A. Afterburners

Combustible material in the gas phase--typically organic gases and vapors--may be eliminated by complete oxidation to give carbon dioxide and water vapor. Equipment designed for this purpose is generally known as an afterburner (or fume and vapor incinerator).

1. Direct-Fired Afterburners

Direct-fired afterburners are the most common type. They have been successfully applied to control effluents from aluminum chip driers, animal blood driers, asphalt-blowing stills, brake shoe debonding ovens, foundry core ovens, smokehouses, paint-baking ovens, rendering cookers and similar sources.

Principal components are a combustion chamber, a gas burner with appropriate controls, and a temperature indicator. Figure 5.52 illustrates a typical direct-fired afterburner in sectional view. The combustion chamber must provide complete mixing of the contaminated gases with the burning fuel-air mixture in the flame zone. A blower may be needed to deliver the contaminated gases to the afterburner when natural draft is inadequate.

Burners having long, luminous flames appear to incinerate contaminants more effectively than others. Where the load of contaminants to be incinerated varies appreciably during the process cycle, modulating burner controls may be used to effect fuel savings.

A temperature indicator, ordinarily a bare-wire thermocouple, should be installed near the top of the chamber in such a position

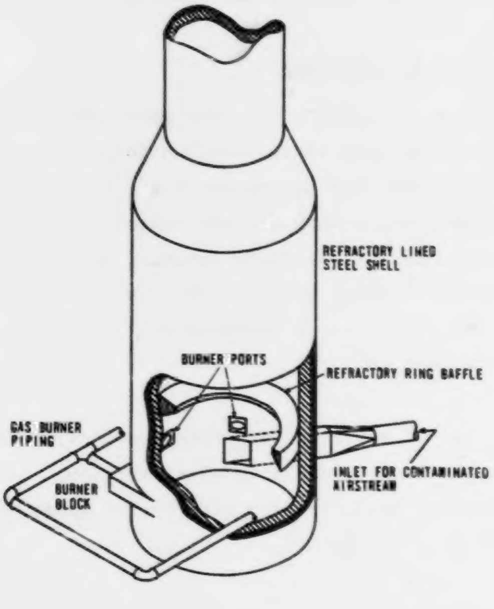

REFRACTORY LINED STEEL SHELL
BURNER PORTS
REFRACTORY RING BAFFLE
GAS BURNER PIPING
INLET FOR CONTAMINATED AIRSTREAM
BURNER BLOCK

Figure 5.52. TYPICAL DIRECT-FIRED AFTERBURNER WITH TANGENTIAL ENTRIES FOR BOTH THE FUEL AND CONTAMINATED GASES. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

as to measure gas temperature while avoiding direct flame radiation. A safety pilot is usually provided. To shut off the fuel supply when the contaminated gas stream is interrupted, a high-temperature limiting control may be incorporated.

2. Catalytic Afterburners

The use of a catalyst promotes many combustion reactions at lower temperatures than those required for direct-flame incineration. In some cases this may accomplish satisfactory combustion at less fuel cost than a direct-flame device. Incomplete combustion, however, must be carefully avoided, as odor potentials of the contaminated gases may sometimes be increased by passage through a catalytic afterburner operated at too low a temperature (or with insufficient air).

A typical catalytic afterburner consists of a housing comprising a preheater section and a catalyst section. Arrangements for the recovery of heat from the afterburner gases may be incorporated, as shown in Figure 5.53.

The contaminated gases are preheated to reaction temperature by a gas burner. Operating temperatures are usually between 650°F and 1000°F. The catalyst is most commonly platinum, but other formulations utilize copper chromite or oxides of various metals. Catalyst activity declines with use, raising the necessity for occasional regeneration and eventual replacement of the catalyst.

Where the contaminant load is variable, burner controls may be regulated by the temperature of the gas discharged from the catalyst. The amount of fuel used to preheat the contaminated gas is thus reduced when the contaminant concentration increases, releasing

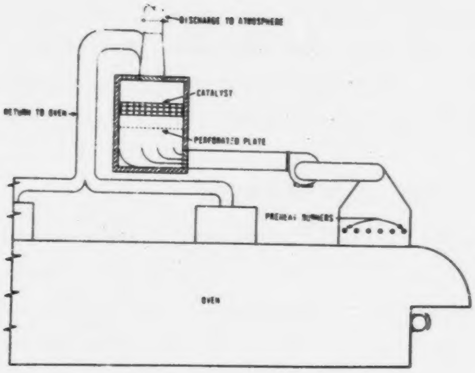

DISCHARGE TO ATMOSPHERE
CATALYST
RETURN TO OVEN
PERFORATED PLATE
PREHEAT BURNERS
OVEN

Figure 5.53. TYPICAL CATALYTIC AFTERBURNER UTILIZING DIRECT HEAT RECOVERY. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

more heat within the catalyst bed. With a preheat burner which operates at fixed input, a high-temperature limiting control may be needed to prevent overheating of the catalyst.

The contaminated gas stream must be free of substances which might act as poisons for the particular catalyst in use. Particularly troublesome are fumes or vapors of certain metals, including mercury, arsenic, zinc and lead. For optimum efficiency in combustion, air should be provided in excess of the amount theoretically necessary for complete combustion.

3. Boilers Used as Afterburners

Boiler firebox conditions are, in some cases, similar to those required of contaminant incinerators. Under certain conditions such equipment may be adapted for contaminant incineration. For a successful adaptation, the contaminated gas must be essentially free of non-combustible dust or fumes, its volume must be moderate and its oxygen content near that of air, and the minimum firing rate of the boiler must be great enough to incinerate the maximum volume of effluent to be expected.

Installations of this type have been successful in application to control of effluents from smokehouses, rendering cookers and various process units in oil refineries.

B. Absorption Equipment

Absorption is the process of removing contaminants from a gas stream by causing them to dissolve in a liquid. Both gaseous and vapor contaminants may be separated by absorption methods. The effectiveness of the method for a particular contaminant depends upon the use of a liquid which is a specific solvent for that contaminant, i.e., the contaminant must be very much more soluble than the air or other non-contaminant gases which carry the contaminant.

The gaseous air contaminants most commonly controlled by absorption include sulfur dioxide, hydrogen sulfide, hydrogen chloride, chlorine, ammonia, oxides of nitrogen and light hydrocarbons. Vaporous contaminants may be recovered from the solution after absorption, when their value warrants such a procedure. The most useful absorbents are ordinarily of low volatility, non-corrosive, inexpensive, of low viscosity, non-toxic, non-flammable, chemically stable and not subject to freezing at ordinary temperatures.

Absorption equipment is designed to provide thorough contact between the gas and liquid phases, as the rate of removal is largely dependent upon the amount of surface exposed. The necessary contact can be accomplished by dispersing gas in liquid (bubbling) or liquid in gas (spraying). In packed towers, on the other hand, both gas and liquid phases are continuous

1. Packed Towers

A packed tower is filled with small solid objects (packing) designed to expose a large surface area, which is kept wet by a continuous flow of the absorbent, as shown in Figure 5.54.

Usually the flow through a packed column is countercurrent, with the liquid introduced at the top to trickle down through the packing, while gas is introduced at the bottom to pass upward through the packing. This results in high efficiency, since, as the solute concentration in the gas stream decreases as it rises through the tower, there is constantly fresher solvent available for contact.

In concurrent flow, the gas stream and the absorbent both enter at the top of the column. This is seldom used, except for the solution of special design problems.

Packing materials are readily available as ceramic objects of various standard shapes, such as those illustrated in Figure 5.55. Most common are Raschig rings, consisting of hollow cylinders having external diameters equal to their length. Packing may be dumped into the column for randomness or may be manually stacked in an orderly pattern. Dumped packing ordinarily has a higher specific surface contact area, but causes a higher gas pressure drop across the bed.

To ensure complete wetting, liquid must be introduced into the tower at not less than 5 pints per square foot of cross section. The liquid flow rate must be sufficient to wet the packing, but not enough to flood the tower, as this causes bubbling and drastically increases the pressure drop.

2. Plate Towers

Plate towers employ stepwise gas-liquid contact by means of a number of trays or plates arranged to disperse gas through a liquid layer on each plate. Most common is the bubble-cap plate tower, illustrated in Figure 5.56. Each plate is equipped with openings (vapor risers) surmounted with bubble caps. Gas rises through the tower, passing through the openings in the plates and through slots in the periphery of the bubble caps, which are submerged in liquid. The liquid enters at the top of the tower, flows across each plate and downward from plate to plate through downspouts. Depth of the liquid and patterns of flow across the plates are controlled by weirs.

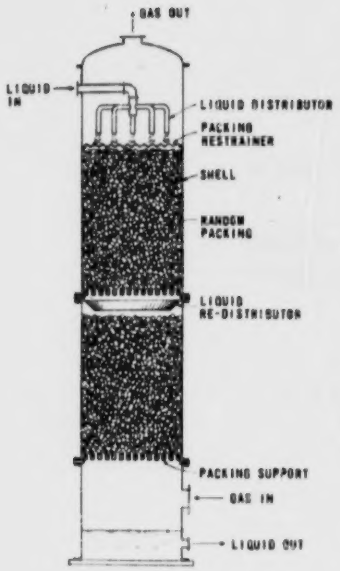

GAS OUT
LIQUID IN
LIQUID DISTRIBUTOR
PACKING RESTRAINER
SHELL
RANDOM PACKING
LIQUID RE-DISTRIBUTOR
PACKING SUPPORT
GAS IN
LIQUID OUT

Figure 5.54. SCHEMATIC DIAGRAM OF A PACKED TOWER, TREYBAL, 1955, p. 134 (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

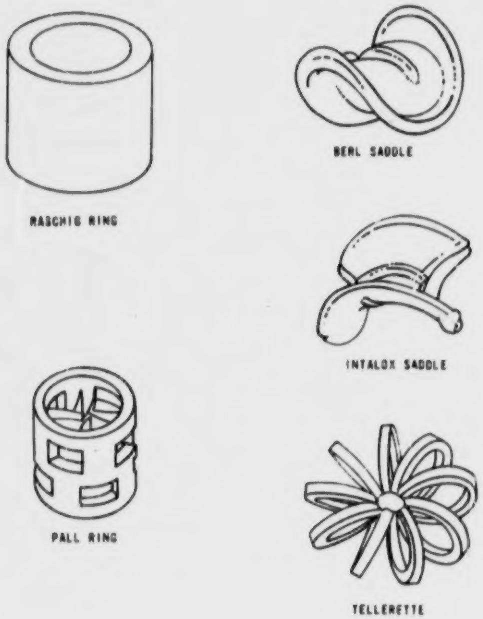

RASCHIG RING
BERL SADDLE
INTALOX SADDLE
PALL RING
TELLERETTE

Figure 5.55. COMMON TOWER PACKING MATERIALS, TELLER, 1960, p. 122 (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

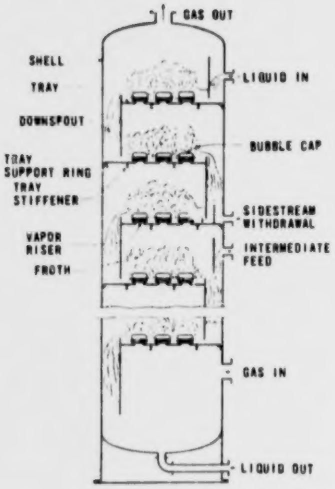

GAS OUT
SHELL
TRAY
LIQUID IN
DOWNSPOUT
BUBBLE CAP
TRAY
SUPPORT RING
TRAY
STIFFENER
SIDESTREAM
WITHDRAWAL
VAPOR
RISER
INTERMEDIATE
FEED
FROTH
GAS IN
LIQUID OUT

Figure 5.56. SCHEMATIC DIAGRAM OF A BUBBLE-CAP TRAY TOWER, TREYBAL, 1955, p. 111 (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

In perforated plates or sieve trays, the gas passes upward through a pattern of holes in the trays. Such towers are less costly to fabricate, but are more subject to channeling than bubble-cap towers and may be less efficient in prolonged operation. Various other designs have also been promoted on a proprietary basis.

3. Spray Towers and Chambers

Contact between a gas stream and a liquid absorbent in droplet form is achieved in spray towers or spray chambers. For greatest efficiency of absorption, droplets must be very small, with diameter about 1 millimeter or less. Such fine droplets require a high pressure drop across spray nozzles, and gas velocities must be kept low to avoid liquid entrainment. In one design, spray droplets are forced to the chamber walls by the centrifugal action of tangentially entering gas to avoid entrainment loss from the top of the chamber. Application of such devices in air pollution control is uncommon.

4. Spargers

Probably the simplest method of dispersing a gas in a liquid for absorption is by injecting the gas through a perforated pipe, or sparger, into a vessel filled with the liquid. For best efficiency of absorption, the bubbles must be very fine; this requires a high pressure drop in the gas stream. However, increased dispersion can also be achieved by injecting the gas below a rotating propeller, where the blade breaks up larger bubbles.

Absorption in a single vessel is usually not very effective, but substantial separations can be achieved with a series of vessels in a countercurrent arrangement.

Such vessels have been used to remove odorous products in the manufacture of specialty lubricants, with a caustic soda solution as the absorber. Acid gases may be similarly controlled with adequate efficiency by alkaline solutions.

5. Venturi Absorbers

In a venturi scrubber, gases are cleaned by passage through a venturi tube to which low-pressure water is added at the throat. For fine dusts, very high collection efficiencies have been reported, and gases which are highly water-soluble may also be removed in this way. High power requirements for operation of such a device constitute a disadvantage which is usually decisive, unless the dust problem is an important consideration.

C. Adsorption Equipment

Adsorption is the process of removing contaminants from a gas stream by passing it through a bed of granules of a highly porous solid, called an adsorbent. In the general case, an adsorption process is usually followed by a regeneration process, in which the activity of the adsorbent is restored by driving the adsorbate (the contaminant) out of the bed, with or without recovery of the adsorbate.

Activated charcoal is the adsorbent most suitable for removing organic vapors, as it affords practical control for all vapors of compounds having boiling temperatures above the temperature of melting ice. Even more volatile contaminants can be effectively adsorbed if the temperature of the adsorbent is lowered.

A number of processes in food technology are associated with odorous effluents which can be readily controlled by adsorption. In this category are meat processing, food canning, dehydration, cooking, baking and roasting, processing of spent mash, fat rendering and waste digestion. Odorous materials used or produced in many chemical manufacturing and commercial uses may be similarly controlled.

Activated charcoal impregnated with a suitable alkaline material is an excellent adsorbent for acid gases, such as sulfur dioxide, hydrogen chloride and hydrogen fluoride. Other commercially important adsorbents are silicas, aluminosilicates, metal oxides, etc. These substances show considerably greater selectivity than does activated charcoal and are, therefore, far less useful than charcoal for over-all decontamination of air. They are essentially ineffective for direct decontamination of any gas stream containing appreciable water vapor.

When air containing a contaminant vapor is passed over a bed of charcoal, adsorption is initially complete. As the retentive capacity of the carbon is reached, traces of vapor appear in the exit air. This stage of adsorption is called the breakpoint, beyond which the efficiency of removal decreases rapidly. As the flow of air is continued, additional vapor is adsorbed, but the concentration of vapor in the exit air (Figure 5.57) increases until it eventually equals that in the inlet. In this condition, the adsorbent is said to be saturated and is of no further use until regenerated.

If pure air is passed through a charcoal bed initially saturated with a vaporous contaminant, a large part of the adsorbed substance may be readily removed, but another fraction will remain. The ratio of the weight of adsorbate retained to the weight of the adsorbent is known as the retentivity, or retentive capacity.

During adsorption of a vapor, heat is liberated, which can increase the temperature of the adsorbent bed. Vapor concentrations encountered

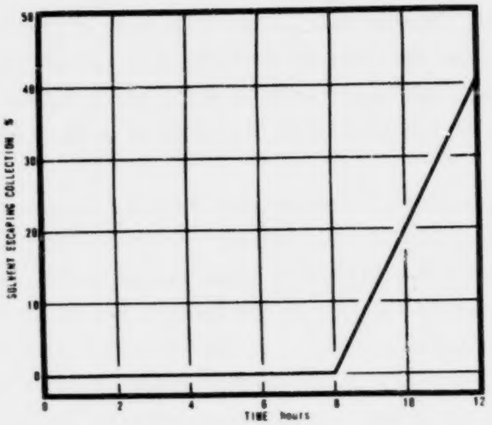


Figure 5.57. ADSORPTION EFFICIENCY, SINGLE SOLVENT, REPORT NO. 8, EXPERIMENTAL PROGRAM FOR THE CONTROL OF ORGANIC EMISSIONS FROM PROTECTIVE COATING OPERATIONS, LOS ANGELES COUNTY, AIR POLLUTION CONTROL DISTRICT, LOS ANGELES, CALIF., 1961 (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

in paint spraying or coating operations result in a temperature rise of about 15°F (8) and do not seriously affect the capacity of the adsorbent. On the other hand, the use of activated carbon to capture vaporized organic compounds at relatively large concentrations, such as the discharge from the filling of gasoline tanks, can result in a temperature rise that can reach dangerous levels.

Regeneration is accomplished by passing a hot gas through the carbon bed. Saturated steam at low pressure, up to 5 psig, is the usual medium. Steam superheated to as high as 650°F, however, may be necessary to reactivate carbon to its original condition, especially when the adsorbate contains high-boiling constituents such as are found in mineral spirits. Normally, the flow of steam passes in a direction opposite to the flow of gases during adsorption.

1. Fixed-Bed Adsorber

The enclosure for a simple fixed-bed adsorber may be a vertical or a horizontal cylindrical vessel. For more than one bed in a single housing, a vertical arrangement is usual.

For the capture of vapors in a continuous operation, it is customary to use 2 or more fixed-bed units, so that one may be adsorbing on stream while the other is being stripped of adsorbate and regenerated. A schematic diagram of such a unit is shown in Figure 5.58.

Regeneration and cooling of the adsorbent determines the cycle time for this type of system. Regeneration releases the bulk of the adsorbed vapor rapidly; usually, no attempt is made to remove all the adsorbate. Normally 2 absorbing units are sufficient, but with 3 units it is possible to have 1 adsorbing, 1 cooling and 1 regenerating. Vapor-free air from the adsorbing unit can then be used to cool the unit just regenerated.

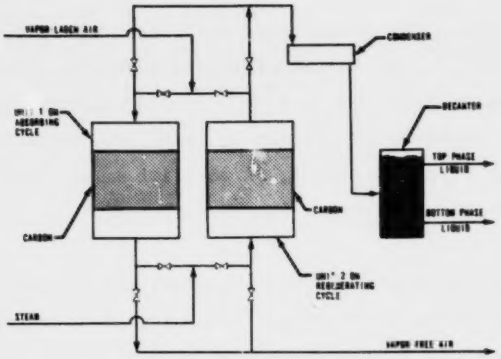

VAPOR LADEN AIR
CONDENSER
UNIT 1 ON ADSORBING CYCLE
DECANTER
TOP PHASE LIQUID
CARBON
BOTTOM PHASE LIQUID
CARBON
UNIT 2 ON REGENERATING CYCLE
STEAM
VAPOR FREE AIR

Figure 5.58. DIAGRAMMATIC SKETCH OF A TWO-UNIT, FIXED-BED ADSORBER. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

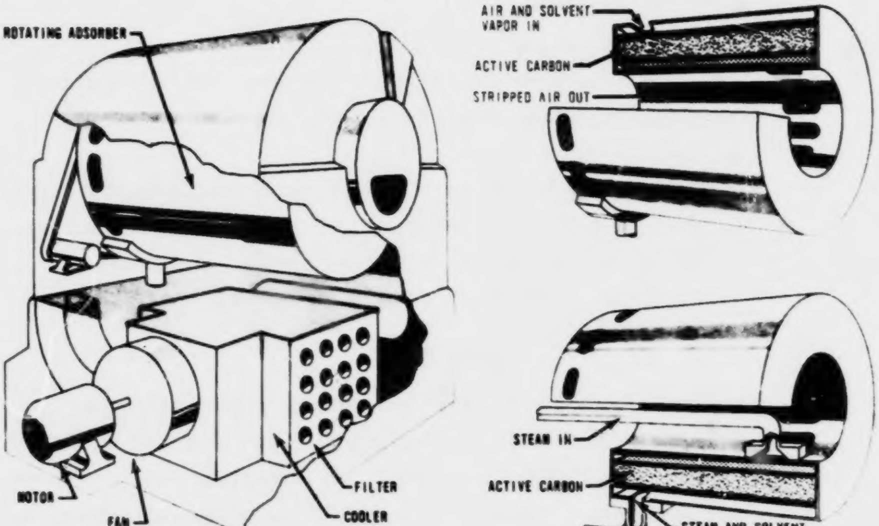

ROTATING ADSORBER
MOTOR
FAN
FILTER
COOLER
AIR AND SOLVENT VAPOR IN
ACTIVE CARBON
STRIPPED AIR OUT
STEAM IN
ACTIVE CARBON
STEAM AND SOLVENT VAPOR OUT

Figure 5.59. LEFT: DIAGRAMMATIC SKETCH OF A ROTATING FIXED-BED CONTINUOUS ADSORBER SHOWING THE PATH OF THE VAPOR-LADEN AIR TO THE CARBON BED. RIGHT: CUT OF CONTINUOUS ADSORBER SHOWING PATH OF STEAM DURING REGENERATION, SUTCLIFFE, SPEAKMAN CANADA, LTD., HAMILTON, ONTARIO (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

2. Continuous Adsorber

A continuous, activated-carbon, solvent recovery unit is available. Figure 5.59 shows the cutaway view of the unit. Filtered air containing the solvent is delivered into the enclosure and enters ports to the carbon section. It then passes through the cylindrical bed to the inside space. Vapor-free air travels axially to the drum and is discharged. In regeneration, the steam enters through a row of ports by means of a slide valve as the cylinder rotates. Solvent and steam leave through a second row of ports and are separated continuously by decantation.

3. Operational Problems

The adsorbent should be protected by filtration of the gas stream from accumulation of particulate matter, which can interfere with adsorption and reduce the life of the carbon.

Corrosion of adsorbers may also be a problem, due to the steam used in regeneration; this is intensified when superheated steam is used. Corrosion can be reduced or controlled by the use of stainless steel in construction or by application of a protective coating of a baked phenolic resin.

D. Condensers Used in Vapor Recovery Systems

Condensation is the process of removing a vaporous material from a gas stream by cooling it, thereby converting it into a liquid phase. In some instances, control of volatile contaminants can be satisfactorily achieved entirely by condensation. However, most applications require additional control methods. In such cases, the use of a condenser as part of the control system, or vapor recovery system, can confer such benefits as reducing the load on a more expensive control device, or reducing the concentration of corrosive or otherwise troublesome constituents in the gas stream entering the control device.

1. Surface Condensers

Condensers used in air pollution control systems operate through removal of heat from the gas stream and they differ principally in the means of cooling. In surface condensers, the coolant does not contact the vapors or condensate.

Most surface condensers are of the tube and shell type shown in Figure 5.60. Water flows inside the tubes, and vapors condense on the shell side. Cooling water is normally chilled, as in a cooling tower, and reused. Air-cooled surface condensers provide for condensation within the tubes; these are usually constructed with extended surface fins to facilitate heat transfer. A typical fin-tube design is shown in Figure 5.61.

A section of an atmospheric condenser is shown in Figure 5.62. Here, vapors condense inside tubes cooled by a curtain of falling water, which is cooled by air circulating through the tube bundle.

2. Contact Condensers

Contact condensers employ liquid coolants, usually water, which come in direct contact with condensing vapors. These devices are relatively uncomplicated, as shown by the typical designs of Figure 5.63 and Figure 5.64. Some are simple spray chambers, usually with baffles to ensure adequate contact; others are high-velocity jets designed to produce a vacuum.

In comparison with surface condensers, contact condensers are more flexible, simpler and considerably less expensive. On the other

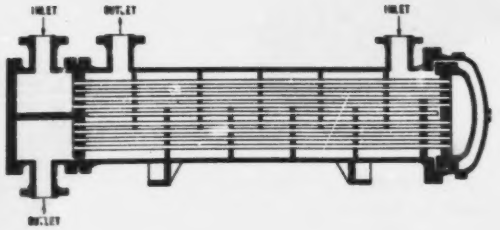

INLET
OUTLET
INLET
OUTLET

Figure 5.60. TYPES OF CONDENSERS. SURFACE CONDENSERS: SHELL AND TUBE, SCHUTTE AND KOERTING CO., CORNWELL HEIGHTS, PENN. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

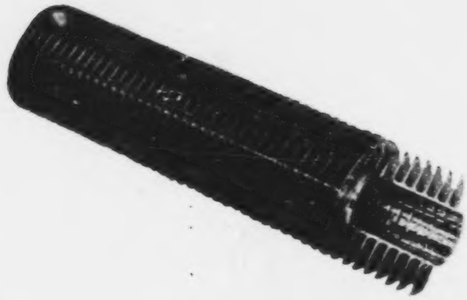


Figure 5.61. TYPES OF CONDENSERS. SURFACE CONDENSERS: INTEGRAL FINNED SECTION, CALUMET & HECLA INC., ALLEN PARK, MICH. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

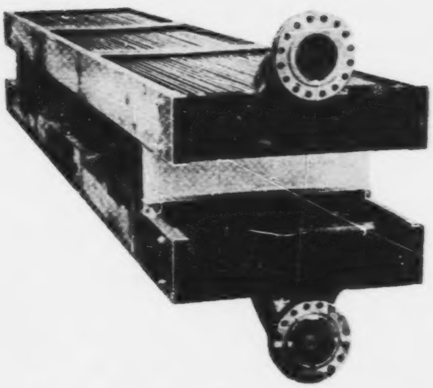


Figure 5.62. TYPES OF CONDENSERS. SURFACE CONDENSERS: TUBULAR, HUDSON ENGINEERING CORP., HOUSTON, TEXAS. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

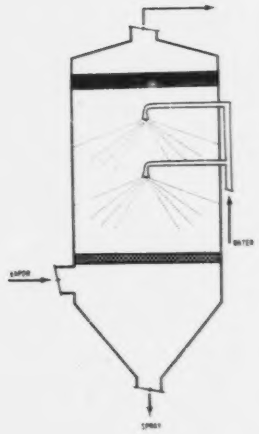


Figure 5.63. TYPES OF CONDENSERS. CONTACT CONDENSERS: SPRAY, SCHUTTE AND KOERTING CO., CORNWELL HEIGHTS, PENN. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

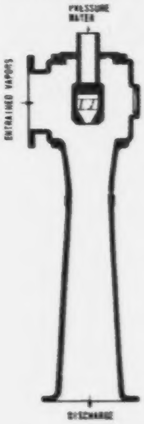


Figure 5.64. TYPES OF CONDENSERS. CONTACT CONDENSERS: SPRAY, SCHUTTE AND KOERTING, CO., CORNWELL HEIGHTS, PENN. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

hand, surface condensers require far less water and produce a far smaller volume of condensate. Condensate from contact units, diluted with water as it is, cannot be reused and may constitute a waste disposal problem. Surface condensers can be used to recover a valuable condensate, but they must be equipped with more auxiliary equipment and they usually require a greater degree of maintenance.

Contact condensers normally afford a greater degree of air pollution control because of condensate dilution. With contact units, about 15 pounds of water at 60°F is required to condense 1 pound of steam and cool the condensate to 140°F. The resultant 15 to 1 dilution greatly reduces the concentration and vapor pressure of the volatile materials, provided they are miscible with water.

3. Typical Installations

Besides collecting condensable contaminants, condensers may materially reduce the volume of the contaminated gas streams. To a degree, contact condensers are also scrubbers. Probably their most common application is as auxiliary units in systems containing afterburners, absorbers, baghouses, or other control devices. A number of possible combinations are diagrammed in Figures 5.65, 5.66, and 5.67.

Installations incorporating condensers have been used successfully for many operations in petroleum refineries, petrochemical plants and chemical manufacturing in general (see Table 5.16). In all such installations, precautions must be taken to ensure that there is no major evolution of vapors from the condensate discharged. In most instances, the condensate is merely cooled to a temperature at which the vapor pressure of the contaminants is satisfactorily low. Most condensed aqueous solutions must be cooled to 140°F or

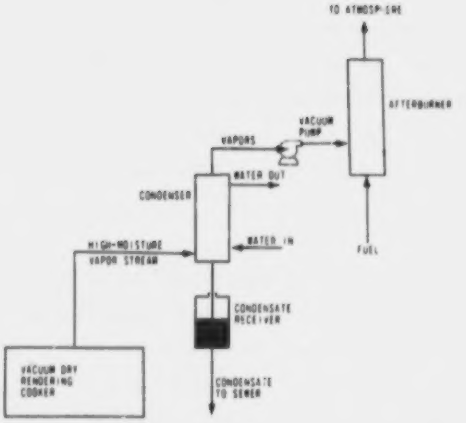

TO ATMOSPHERE
AFTERBURNER
VACUUM PUMP
VAPORS
WATER OUT
CONDENSER
HIGH-MOISTURE VAPOR STREAM
WATER IN
FUEL
CONDENSATE RECEIVER
VACUUM DRY RENDERING COOKER
CONDENSATE TO SEWER

Figure 5.65. A CONDENSER-AFTERBURNER AIR POLLUTION CONTROL SYSTEM IN WHICH A VACUUM PUMP IS USED TO REMOVE UNCONDENSED GASES FROM CONDENSATE. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

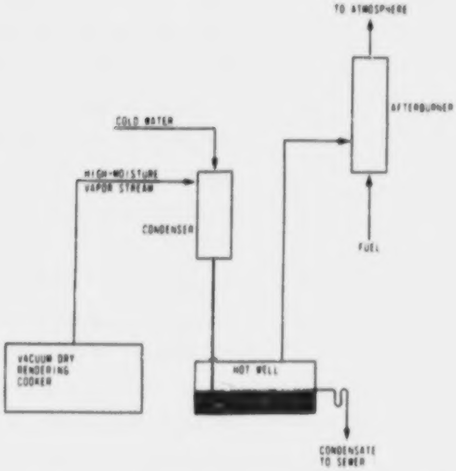

TO ATMOSPHERE
AFTERBURNER
COLD WATER
HIGH-MOISTURE VAPOR STREAM
CONDENSER
FUEL
VACUUM DRY RENDERING COOKER
HOT WELL
CONDENSATE TO SEWER

Figure 5.66. A CONTACT CONDENSER-AFTERBURNER AIR POLLUTION CONTROL SYSTEM IN WHICH MALODOROUS, UNCONDENSED GASES ARE SEPARATED FROM CONDENSATE IN A CLOSED HOT WELL. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

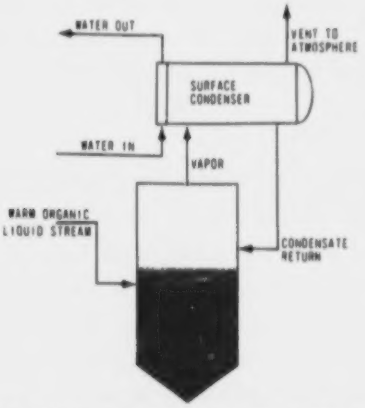

WATER OUT
VENT TO ATMOSPHERE
SURFACE CONDENSER
WATER IN
VAPOR
WARM ORGANIC LIQUID STREAM
CONDENSATE RETURN

Figure 5.67. A SURFACE CONDENSER USED TO PREVENT SURGE LOSSES FROM AN ACCUMULATOR TANK HANDLING WARM, VOLATILE, ORGANIC LIQUID. (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 5)

Table 5.16. TYPES OF PROCESSES OR EQUIPMENT FOR WHICH CONDENSERS HAVE BEEN APPLIED IN CONTROLLING CONTAMINANT EMISSIONS.

REFINERY AND PETROCHEMICAL

Alkylation unit accumulator vents
Amine stripper units
Butadiene accumulator vents
Coker blowdown
Ketone accumulator vents
Lubricating oil refining
Polyethylene gas preparation accumulator vents
Residuum stripper unit accumulator vents
Storage equipment
Styrene-processing units
Toluene recovery accumulator vents
Udex extraction unit

CHEMICAL MANUFACTURING

Manufacture and storage of ammonia
Manufacture of Cooper naphthenates
Chlorine solution preparation
Manufacture of ethylene dibromide
Manufacture of detergents
Manufacture of insecticides
Manufacture of latex
Manufacture of nitric acid
Manufacture of phthalic anhydride
Resin reactors
Soil conditioner formulators
Solvent recovery
Thinning tanks

MISCELLANEOUS

Aluminum fluxing
Asphalt manufacturing
Blood meal driers
Coal tar dipping operations
Degreasers
Dry cleaning units
Esterification processes
Pectin preparation
Rendering cookers
Vitamin formulation

less before venting to the atmosphere; for volatile organics, even lower temperatures are necessary. Uncondensable contaminants are normally vented to further control equipment, as in Figures 5.65 and 5.66.

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CHAPTER 6

INSPECTION PROCEDURES FOR GENERAL SOURCES

I. INTRODUCTION

General inspection procedures apply to emission sources which are common to many air quality regions, are large in number, and tend to be distributed throughout any given air quality control region. These are sources which are most subject to general surveillance, observation of visible emissions, source testing and nuisance complaints. The sources may constitute independent or captive operations and possess a wide range of design characteristics, capacities, applications and emission potentials. Emission sources of this type which are treated in this chapter include fuel-burning equipment, incinerators, open burning activities, odor nuisance sources, and motor vehicles.

With the exception of certain aspects of odor nuisances, combustion of fuels and refuse is the central process to be considered. Inspection procedures described in this chapter, therefore, are mostly oriented to fuel properties; preparation and distribution of fuels; type, design and capacities of firing systems; firebox and combustion conditions; management of combustion air, and use of air pollution control equipment and techniques.

II. FUEL-BURNING EQUIPMENT

A. INTRODUCTION

Fuel-burning equipment, as treated in this chapter, consist of equipment designed for the purposes of steam generation, electric power generation, space heating, service water heating and other thermal processes. Liquid, solid or gaseous fuel is burned in the firebox of a boiler to generate heat. The heat, in turn, is transferred through heat absorbing furnaces, or heat exchangers, to a fluid such as air, water or liquid chemicals. In this form of indirect heating, the products of combustion cannot contact the fluid to be heated and are exhausted through a stack to the ambient air.

Fuel-burning encompasses the combustion of conventional fuels such as coal, fuel oil and natural gas, but also includes waste wood products, refuse and other liquid or solid materials if these are used to provide space or process heat and a heat exchanger or other method of indirect heating is employed. Combustion systems in which a material is burned for the primary purpose of reducing the material to ash are known as incinerators and are treated in Section III of this chapter.

Most air pollutants emitted from fuel-burning installations result from the incomplete combustion of fuel. When complete combustion occurs only carbon dioxide, water vapor and small amounts of ash are emitted. (Common chemical reactions occurring during combustion are shown in Table 6.2.1.) Conditions approaching complete combustion can be maintained throughout the fuel burning cycle--ignition, burning and burndown--provided that:

- Temperature is high enough to ignite and burn all of the fuel.
- Sufficient time is allowed to complete burning of all of the fuel.
- Sufficient turbulence is permitted to allow thorough mixing of fuel particles with combustion air.
- Sufficient oxygen is provided for a proper air fuel ratio.

Table 6.2.1. COMMON CHEMICAL REACTIONS OF COMBUSTION

COMBUSTIBLE	REACTION
Carbon (to CO)	$2C + O_2 = 2CO + Q$
Carbon (to CO_2)	$C + O_2 = CO_2 + Q$
Carbon monoxide	$2CO + O_2 = 2CO_2 + Q$
Hydrogen	$2H_2 + O_2 = 2H_2O + Q$
Sulfur (to SO_2)	$S + O_2 = SO_2 + Q$
Sulfur (to SO_3)	$2S + 3O_2 = 2SO_3 + Q$
Methane	$CH_4 + 2O_2 = CO_2 + 2H_2O + Q$
Acetylene	$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O + Q$
Ethylene	$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O + Q$
Ethane	$2C_2H_6 + 7O_2 = 4CO_2 + 6H_2O + Q$
Hydrogen sufide	$2H_2S + 3O_2 = 2SO_2 + 2H_2O + Q$

Where Q = the heat of reaction

Source: Babcock and Wilcox Company, Reference 1.

B. ELEMENTS OF THE COMBUSTION SYSTEM

A combustion system feeds fuel, mixes fuel with air and ignites and burns the fuel in a firebox at rates necessary to generate the amount of thermal energy required. Several types of systems are in common use. Gas, oil, pulverized coal or crushed coal burners are affixed to a furnace opening and fired under fuel or pneumatic pressure directly into the furnace. Stoker systems mix, classify and transport solid fuels into and through the boiler firebox and provide for continuous dumping and removal of ash residue. Specific firing systems are described in greater detail in part F of this section.

Common elements of fuel-burning systems are shown in Figure 6.2.1. The combustion system in actuality is a control or feedback system intended to maximize combustion efficiency and production of thermal energy and to minimize air pollution emissions. Principal options as between manual and automatic process control systems, and additional heat exchange and air heating units used in large central power stations are shown in Figure 6.2.1. Systems may be fully automatic (operated from a central control panel) or semi-automatic or manual. The latter are found in medium-sized or small installations where trained operators make the necessary combustion system adjustments.

The following terms define the principal features and aspects of the fuel-burning system.

1. FUEL--this consists of liquid, gaseous and solid fuels treated in part C of this section.
2. FUEL PREPARATION AND FEED--these include preheating liquid fuels, or crushing, grinding, classifying, washing or otherwise conditioning solid fuels prior to combustion. Washing includes purifying, cleaning or removing impurities from coal by mechanical processes, regardless of the cleaning medium used. (See also Coal Preparation Plants, Chapter 7, Section XIII.)
3. FEEDWATER--the water supplied to the heat exchanger units for heating or steam production.

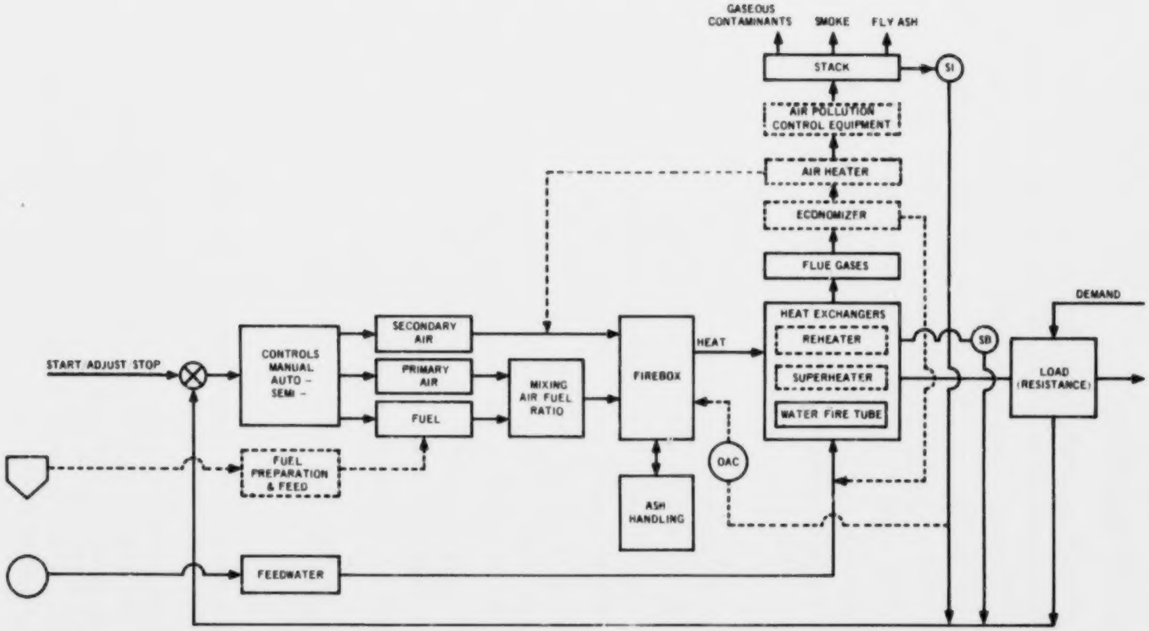

GASEOUS CONTAMINANTS
SMOKE
FLY ASH
STACK
SI
AIR POLLUTION CONTROL EQUIPMENT
AIR HEATER
ECONOMIZER
FLUE GASES
DEMAND
HEAT EXCHANGERS
REHEATER
SUPERHEATER
WATER FIRE TUBE
SB
LOAD (RESISTANCE)
START ADJUST STOP
CONTROLS MANUAL AUTO – SEMI –
SECONDARY AIR
PRIMARY AIR
FUEL
MIXING AIR FUEL RATIO
FIREBOX
HEAT
OAC
ASH HANDLING
FUEL PREPARATION & FEED
FEEDWATER

Figure 6.2.1. SIMPLIFIED SCHEMATIC OF COMBUSTION HEAT EXCHANGE SYSTEM ELEMENTS. BROKEN BLOCKS ARE ADDITIONAL COMPONENTS USUALLY FOUND IN LARGE STEAM GENERATING INSTALLATIONS. SI = Smoke Indicator; SB = Soot Blower; OAC = Overfire Air Control (Used in Stoker Installations).

4. COMBUSTION AIR--several types of combustion air are of interest. Primary air is air which is introduced with the fuel at the burner, or over the fuel bed. Secondary air or draft is air which is introduced to the furnace through ports or tuyeres. Secondary air may be supplied by means of forced draft, induced draft, or natural draft. Forced draft is air injected into the furnace by means of fans. Induced draft is air drawn through the furnace by means of a fan located on the flue side of the boiler. Dampers (barometric butterfly, guillotine, sliding etc.) regulate the flow of combustion air into and through the various compartments of the furnace as well as the flow of flue gases out of the furnace. Overfire air control (OAC in Figure 6.2.1), used in stoker equipment, releases air from jets over the fuel beds. These are usually controlled by manual means, electric timer, or by activation of a smoke indicator (SI in Figure 6.2.1). Excess air is air for effective combustion and the amount of excess air over that theoretically required for complete combustion is a factor in the emission of all air contaminants. Excess air can be determined from oxygen analyzers located in the power plant. Optimum excess air requirements should be established for each installation. Table 6.2.2 is a guide to recommended amounts of excess air for various types of fuel-burning installations.

5. FIREBOX--this is usually of refractory cement, water wall, water tube or firebrick construction. Type and condition of firebox and flame clearance in feet should be noted.

6. HEAT EXCHANGERS--these are basic boiler or steam generating units which transfer heat through surfaces to the feedwater to produce steam. Heat transfer may be by convection or radiation. Superheaters found in large installations are tubular elements which produce high pressure steam (potential pressure) from the initial heating of the water. They are an integral part of the boiler system. Radiant exchangers are located in the furnace. Convection exchangers are located in flue gases where comparatively low gas temperatures occur.

7. REHEATERS--reheaters heat steam which has been used to do work as in turbines.

8. ECONOMIZERS--economizers preheat feedwater from the low-temperature flue gases leaving the steam generating unit.

9. SOOT BLOWERS--sootblowers (SB in Figure 6.2.1) are lances which release jets of steam or air to remove soot deposited on heat exchanger surfaces. These are usually of a retractable type in large installations. The lances move across tube surfaces to remove particulates. Usually 8 to 15 blowers are used in large installations. Soot blowing may be conducted at least once every 24 hours or may be operated automatically at 2-4 hour intervals. Soot blowing schedules should be checked.

Table 6.2.2. USUAL AMOUNT EXCESS AIR SUPPLIED TO FUEL-BURNING EQUIPMENT

Fuel	Type of Furnace or Burners	Excess Air, % by Wt
Pulverized coal	Completely water-cooled furnace for slag-tap or dry-ash-removal	15-20
	Partially water-cooled furnace for dry-ash-removal	15-40
Crushed coal	Cyclone Furnace—pressure or suction	10-15
Coal	Stoker-fired, forced-draft, B&W chain-grate	15-50
	Stoker-fired, forced-draft, underfeed	20-50
	Stoker-fired, natural-draft	50-65
Fuel oil	Oil burners, register-type	5-10
	Multifuel burners and flat-flame	10-20
Acid sludge	Cone- and flat-flame-type burners, steam-atomized	10-15
Natural, Coke-oven, & Refinery gas	Register-type burners	20-90
	Multifuel burners	7-12
Blast-furnace gas	Intertube nozzle-type burners	15-18
Wood	Dutch-oven (10-23% through grates) and Hofft-type	20-25
Bagasse	All furnaces	25-35
Black liquor	Recovery furnaces for kraft and soda-pulping processes	5-7

Source: Babcock and Wilcox Company, Reference 1. (Modified)

10. LOAD--this is the demand for steam or energy imposed on the combustion system. It is measured in pounds steam, electrical energy or resistance or pressure drop. Load may be varied by altering firing rates, or by tilting burners in various positions which modulate the heat released to heat exchanger surfaces. Load may be measured in inches of water gage or other devices, and is the principal feedback regulator of the combustion system, as shown in Figure 6.2.1. The inspector should note peak, fluctuating or other abnormal conditions which may affect emissions.

11. AIR HEATERS--these recover heat from the flue gases and recycle them as combustion air to the furnace. Air heaters and economizers help to reduce fuel requirements and improve combustion efficiency and are found in all boilers and heaters of 100 million Btu/hr. and greater gross input. Combustion air temperatures augmented by air heaters may contribute to the formation of NO_x emissions.

12. STACK--stacks may run 25 to 1,000 feet in height and are of brick, steel or transite construction. Stack height is usually the vertical distance measured in feet between the point of discharge from the stack or chimney into the outdoor atmosphere and the elevation of the land thereunder. Effective Stack Height is the sum of the stack height and the plume rise. Plume rise is the calculated distance in feet of the vertical ascent of the air contaminants above the stack or chimney.

13. BOILER CONTROLS--these are essentially dampers, valves and orifices which control fuel flow, combustion air flow, feedwater flow, furnace draft or pressure and steam temperature. Instruments used to monitor steam boilers are similar to those described in part E of Section III, Incinerators. Conditions monitored include:

    steam pressure
    steam temperature (if other than saturated)
    water level
    feedwater pressure
    *furnace draft or pressure

    For units producing more than 10,000 lbs. steam per hour, instruments monitor:

    steam flow
    feedwater flow
    *combustion-air flow
    *component drafts or pressures
    feedwater temperature
    **flue gas temperature

**fuel flow (if possible)
**fuel pressure (if involved)
*fuel temperatures (if involved)
**speed and amperage indicators for fans, pumps, feeders, and other power consuming auxiliaries
*flame detector or flame temperature measurement if available
*continuous stack analyzers (if performed)
**flue gas analysis (may be manual)
*smoke-density control systems or alarms
*oxygen and combustion analyzers

The single asterisks designate instruments or conditions that should be routinely checked, particularly in connection with violations and nuisance complaints. Double asterisks are items that may be involved in emission inventories, source registration, source testing, or other intensive investigations. Items without asterisks provide low priority information that may be of interest to enforcement personnel.

14. CONTAMINANTS EMITTED--the principal types of air contaminants resulting from incomplete combustion include:

a. Smoke--incompletely burned solid and gaseous material which forms a visible plume, usually dark or black in color. Visible emissions from the stacks of fuel-burning equipment may vary from a light haze (less than #1 Ringelmann) indicating an efficient combustion rate to #5 Ringelmann.

b. Particulates--these are solid particles which are incombustible or incompletely burned liquid or solid particles. The various forms of particulates emitted from fuel-burning equipment include:

(1) Soot--small, fine, carbon particles resulting from soot blowing.

(2) Coarse Solid Particles--particles generally equal to or greater than 44 microns; they may also consist of solid particles contained in liquid particles.

(3) Fly Ash--a noncombustible mineral material, usually grey, flakey or powdery in form. The term is sometimes used to refer to all particulates.

(4) Cenospheres--large particles consisting of "skeletons" of burned-out fuel particles that have hollow, black, coke-like spherical properties. Cenosphere emissions are usually associated with atomization in oil burning operations.

(5) Acidic Smut--large particles, 1/4" in diameter, containing metallic sulfate and carbonaceous material. SO_3, condensed with water on furnace surfaces maintained below the temperature of the dew point of the flue gas, acidifies the soot particles. Acidified particles are usually discharged during soot blowing and may spot painted or metallic particles or damage vegetation. Smuts may be prevented by maintaining temperatures of the furnace surfaces above the dew point of the flue gases.

(6) Combustible Particulates--particles of unburned or incompletely burned fuel due to poor maintenance, operation or incorrect selection of burner or fuel.

(7) Trace Metals--trace metals found in coal that have possible health effects include nickel (as nickel carbonyl), beryllium, boron (as boran), germanium, arsenic, selenium, yttrium, mercury and cadmium. As a group these have potential for carcinogenises, acute and chronic system poisoning, cardiovascular disease, hypertension and nerve disease.(2)

c. Gaseous contaminants--these include:

(1) Carbon Monoxide--product of incomplete combustion.

(2) Sulfur Dioxide (SO_2)--a principal oxide of sulfur formed from the oxidation of the sulfur contained in the fuel burned.

(3) Sulfur Trioxide (SO_3--oxidation product of SO_2). A characteristic "white to brown" detached plume which is believed to consist of finely divided sulfuric acid aerosol. Sulfur trioxide, hydrated in the atmosphere to sulfuric acid aerosol, can cause acid damage downwind from the source. Approximately 2-3% of the sulfur content of the fuel is converted to SO_3. SO_3 is associated with large fuel-burning installations. For example in oil-burning installations(3) that consist of:

- units up to 60,000 lbs. steam/hr., visible emissions due to sulfur compounds are not likely to occur when fuels containing 0.3 to 0.5% sulfur are burned.
- units ranging from 50,000 to 500,000 lbs. steam/hr., opacities may not exceed 30%, with 1.4 to 2.0% sulfur in the fuel.
- steam generating units at 750,000 lbs./hr. and greater may emit gases greater than 40% opacity when fired with oil of more than 1.0% sulfur.

(4) Oxides of Nitrogen (NO_x)--includes NO, NO_2, N_2O, N_2O_5 and NO_3. NO_x is usually reported as NO_2, which is oxidized from the initial emission, NO. NO_x emissions are due primarily to "fixation" of atmospheric oxygen and nitrogen at high combustion temperatures. Concentrations are a function of flame temperature, firebox oxygen concentration, and firebox and burner design. NO_x stack concentrations may range up to over 2,000 lbs.hr. in large steam generating installations and are associated with firebox temperatures approaching or exceeding 3,000°F (at about 2% oxygen with air preheated to 600°F).(3) NO_x emissions from large plants may produce a brownish haze or cloud in the vicinity of the plant. NO_x emissions from fuel-oil burning average about 9 lbs./NO_x per 1,000 pounds oil fired.(4) Emissions from coal-fired equipment are shown in Table 6.2.3.

15. EMISSION FACTORS--emission rates for individual boilers are so variable that only stack tests can provide reliable data. However, the following emission factors can be useful in determining gross emissions.

SO_2^a--38 times the percent of sulfur by weight in the coal = pounds of SO_2/ton of coal burned (assumes 5% of sulfur remains in ash).(6)

NO_x--20 pounds/ton of coal burned.(7)

CO--0.5 pounds/ton of coal burned.(8)

Particulates(9)

Combustion of coal

Pulverized:

General (anthracite and bituminous)	16A[b]	lb/ton of coal burned
Dry bottom (anthracite and bituminous)	17A	lb/ton of coal burned
Wet bottom (anthracite and bituminous):		
Without fly ash reinjection	13A	lb/ton of coal burned
With fly ash reinjection	24A[c]	lb/ton of coal burned
Cyclone (anthracite and bituminous)	2A[d]	lb/ton of coal burned

Table 6.2.3. EMISSION OF NITROGEN OXIDES*

Type of unit	Pounds per million Btu input
Pulverized coal	
Vertical firing	0.38
Corner firing	0.95
Front wall firing	0.68
Horizontal opposed firing	0.65
Cyclone	2.5
Stoker:	
Spreader stoker	0.65
Commercial underfeed	0.30
Residential underfeed	0.36
Hand-fired	0.11

*From Hangebrauk, R. P., et al, J. Air Pollution Control Association, 267-278 1964; Cuffe, S. T. and Gerstle, R. W., "Summary of Emissions from Coal-Fired Power Plants," A.I.H.A., Houston, Texas, 1965.

Source: Engdahl, R. B., Reference 5.

Spreader stoker (anthracite and bituminous):		
Without fly ash reinjection	13A	lb/ton of coal burned
With fly ash reinjection	20A[c]	lb/ton of coal burned

16. RULES--typical types of rules and regulations enforced in the field are shown in Table 6.2.4.

17. STANDARD CONDITIONS AND UNITS--for sampling and analysis of gaseous and particulate pollutants from stack gases to establish compliance with maximum allowable emission standards, units and conditions for testing are usually specified in ordinances. For example, with respect to dusts and fumes, standard conditions may be in terms of 60°-70°F at one atmosphere pressure, 14.7 psia or 760 mm Hg. Conditions may be stated in terms of volume of source gas as standard cubic feet of dry exhaust gas (SCFD) or standard cubic feet per minute (SCFM) which may be calculated as if 50% excess air had been used in fuel burning equipment. Concentrations may be specified in grains per standard cubic foot (Gr/SCF). Combustion contaminants are also calculated at 12% carbon dioxide (CO_2) at standard conditions.

18. AIR POLLUTION CONTROL TECHNIQUES--air pollution control techniques may be applied to reductions of both gross emissions and to specific contaminants. The former will depend on such techniques as improved design of the combustion system, fuel substitution, (e.g., gas for oil, utilization of low ash and low sulfur fuels), reduction of electricity or steam load demand, diversion of electric power generation to facilities outside of the air quality control region, good operational practice, tall stacks and source shutdowns.

    Positive control of continuously operating coal and oil-fired facilities will depend on the application of a specific technique for

---

[a] Emission rates are those from uncontrolled sources, unless otherwise noted.

[b] Where letter A is shown, multiply number given by percent ash in the coal.

[c] Value should not be used as emission factor. Values represent the loading reaching the control equipment always used on this type of furnace.

[d] Revised from 5A.

Table 6.2.4. EXAMPLES OF PRINCIPAL TYPES OF AIR POLLUTION CONTROL RULES/CODES AFFECTING FUEL-BURNING INSTALLATIONS

1. EMISSION LIMITATIONS BY VOLUME/WEIGHT OF STACK GAS

   Maximum sulfur compound concentrations expressed as percent by volume or parts per million; combustion compounds expressed as maximum grains per cubic foot of gas calculated at 12 percent carbon dioxide at standard conditions.

2. EMISSION LIMITATIONS IN RELATION TO BTU OF HEAT INPUT

   Maximum particulate concentrations in pounds per million Btu of heat input; or grains per SCFD in relation to units of specified heat inputs; for example, prohibitions of particulate matter in excess of 0.10 pounds per million Btu per hour emitted from solid fuel-burning equipment; particulate matter in excess of 0.025 pounds per million Btu per hour from equipment rated greater than or equal to 250 million Btu per hour heat input.

3. EMISSION LIMITATION IN RELATION TO FUEL-USE

   Particulates, pounds per 1,000 gallons of oil burned or grains per SCFD at 50 percent excess air; sulfur content by fuel oil grade and viscosity.

4. EMISSION LIMITATION IN RELATION TO TIME PERIOD AND STACK HEIGHT

   Coarse solid particles and fine solid particles computed in relation to stack height and distance in stack height from stack to nearest property line. Allowable emissions of sulfur compounds, expressed in pounds per hour, calculated on the basis of stack height, stack exit velocity, exit gas temperature, and stack height adjustment factor using precalculated tables.

5. EMISSION LIMITATIONS BASED ON RINGELMANN AND OPACITY

   Emissions of shade or density equal to or darker than (#1, #2, #3) Ringelmann or equivalent opacity for periods totaling more than (0, 2, 3) minutes in any one hour.

Table 6.2.4. EXAMPLES OF PRINCIPAL TYPES OF AIR POLLUTION CONTROL RULES/CODES AFFECTING FUEL-BURNING INSTALLATIONS (Continued)

6. LIMITATION OF SULFUR CONTENT IN FUELS

All fuels, maximum percent of sulfur by weight, with separate specifications for distillate fuels, residual fuel oils, and solid fuels. Gaseous fuels containing sulfur compounds in excess of specified grains per 100 cubic feet of gaseous fuel (calculated as hydrogen sulfide at standard conditions).

7. LIMITATION OF ASH, VOLATILE CONTENT AND OTHER FUEL PROPERTIES

Example: solid fuel equipment must remove about 99 percent of particulate matter generated by combustion of the average 10 percent ash coal. Removal may be required of about 80 percent of particulate generated from combustion of high-ash residual fuel oil in large boilers.

8. SOOT EMISSION LIMITATION

Bachrach smoke spot test.

9. FUEL SUBSTITUTION REQUIREMENTS

New installations below heat input rate of specified Btu/hr. capacity are prohibited from using residual oils. Distillate oil or natural gas may be substituted.

10. REQUIREMENTS FOR WASHING OR PREPARING COAL

Coal with specified volatile content in excess of a specified percent of ash or sulfur (dry basis) must be washed and used in approved mechanical fuel-burning equipment.

11. PROHIBITION OF FUEL SALES, IMPORTATIONS, TRANSPORTATION OR USE

Coal containing excess volatile matter, except sizes which pass through 2-inch circular opening or equivalent.

Table 6.2.4. EXAMPLES OF PRINCIPAL TYPES OF AIR POLLUTION CONTROL RULES/CODES AFFECTING FUEL-BURNING INSTALLATIONS (Continued)

12. SOURCE REGISTRATION REQUIREMENTS

All coal, oil and gas burning, except:

- Natural gas and other types of gas, #1 and #2 fuel oil with heat input less than 1 x 10^6 Btu/hr.; or approximately 1,000 cubic feet of gas or 7 gallons of oil per hour equivalent fuel use.
- Coal or wood having a heat input of less than 250,000 Btu/hr.

13. PERMIT SYSTEM

All structures with combustion equipment, except four-family dwelling units or less. All fuel-burning equipment greater than specified Btu input.

14. EQUIPMENT PROHIBITIONS

New coal burning installations smaller than specified Btu/hr. input capacity prohibited. All hand-fired and surface burning equipment prohibited.

15. AIR POLLUTION CONTROL EQUIPMENT REQUIREMENT

Particulate control equipment effective at removing specified percent of particulate matter smaller than specified microns in diameter. Allowance for equivalent desulfurization of stack gases. Authorizes operation of sulfur scavenger or recovery plant to reclaim sulfur compounds capable of reducing sulfur compounds at least 95 percent compared to emissions when plant is not operating.

the control of a specific contaminant or class of contaminants. Separate gas cleaning techniques usually will be required for each of the following: particulates, oxides of sulfur and oxides of nitrogen, with the exception of alkaline scrubbers (see below) which are capable of controlling both particulates and oxides of sulfur.

Particulate control techniques applicable to coal and oil fired equipment include settling chambers, large diameter cyclones, multiple-small-diameter cyclones, wet scrubbers, electrostatic precipitators and fabric filters. The expected performances of various types of gas cleaning devices are shown in Table 6.2.5. The control of oxides of sulfur depends on the conversion of SO_2 to a particulate that can be collected by fly ash collection equipment. Principles of control include reactions of SO_x with calcined limestone (limestone-dolomite injection, wet and dry processes), alkalized alumina sorption (removal of SO_x by sorption on solid metal oxides), catalytic oxidation (conversion of SO_2 to SO_3 using vanadium, nickel or platinum catalysts and collection as sulfuric acid, and caustic scrubbing). Control of NO_x depends on design of the combustion equipment, especially with respect to flue gas recirculation, variations in air flow to burners and steam injection at the burners. Control techniques are further treated in other parts of this section and in Chapter 5, The Technology of Source Control.

C. FUELS

Assuming that fuel-burning equipment is adequately designed and operated, emissions of sulfur dioxide and particulates are most related to the type, grade and properties of the fuel used. Emissions of carbon monoxide and smoke are primarily due to burner and boiler operation and maintenance.

Sulfur trioxide and oxides of nitrogen emissions tend to be significant in fuel-burning installations, and are related to the design of the combustion equipment and arrangement of the burners. In these installations SO_3 is formed from approximately 2-3% of the total fuel's sulfur.(3)

Table 6.2.5. OPTIMUM EXPECTED PERFORMANCE OF VARIOUS TYPES OF GAS CLEANING SYSTEMS FOR STATIONARY COMBUSTION SOURCES

Sources	Removal of uncontrolled particulate emissions, percent						
	Systems in operation					Systems under development	
	Settling chambers	Large diameter cyclones	Small diameter cyclones	Electrostatic precipitators	Stack sprays	8-in. pressure drop scrubbers	Fabric filters
Coal-fired:							
Spreader, chain grate, and vibrating stokers.	50 [a]	60 [a]	85 [a]	99.5 [c]	60 [e]	99+ [g]	99.5 [h]
Other stokers	60 [a]	65 [a]	90 [a]	99.5 [c]	80 [e]	99+ [g]	99.5 [h]
Cyclone furnaces	10 [a]	15 [a]	70 [a]	99.5 [c]	(f)	(f)	(f)
Other pulverized coal units	20 [a]	30 [a]	80 [a]	99.5 [c]	(f)	99+ [g]	99.5 [h]
Oil-fired	5 [b]	10 [b]	30 [b]	75.0 [d]	(f)	(f)	(f)

[a] Estimate based on references 17 and 18.

[b] Efficiency estimated—not commonly used.

[c] Estimate based on reference 15.

[d] Estimate based on private reports of field experience.

[e] Reference 19.

[f] Insufficient data for estimate.

[g] Estimate based on reference 20.

[h] Estimate based on reference 21.

Source: Control Techniques for Particulate Pollutants, Reference 9.

NO_x emissions tend to increase with the flame temperatures of fuels which in turn vary with the carbon/hydrogen ratios of the fuel contents. Coal burns hotter than oil and oil hotter than gas, as shown in Figure 6.2.2.

Excessive smoke and particulate emissions may be due, in many instances, to the firing of fuels which are improper for a given design and function of combustion equipment. Also, even within a given fuel type, grade and specification the quality of the fuel, in terms of ash and sulfur content and the presence of water, sediment and other impurities may change thus necessitating constant surveillance of fuel properties. The objective is to employ fuels which are low in sulfur and ash content and low in moisture and other undesirable impurities.

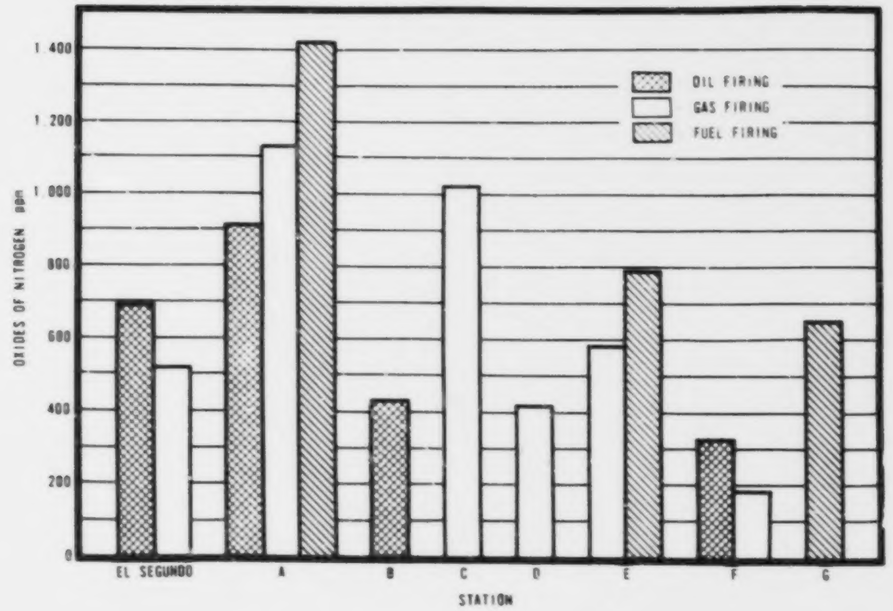


Figure 6.2.2. OXIDES OF NITROGEN CONCENTRATIONS IN GASES FROM VARIOUS GAS-FIRED, OIL-FIRED, AND COAL-FIRED STEAM GENERATORS

SOURCE: WALSH, Reference 3.

Regulations prohibiting sulfur content in fuels will depend on the enforcement agency, available fuels and economic feasibility. Sulfur content restrictions, on a dry weight basis, vary from .2% to 2%. For example, regulations in effect in New Jersey(10) are shown in Tables 6.2.6 and 6.2.7.

Table 6.2.6. SULFUR CONTENT LIMITATIONS FOR COAL

TYPE COAL	PERCENT SULFUR BY WEIGHT (DRY BASIS), COAL	
	Effective 5/6/68	Effective 10/1/71
Bituminous	1.0%	0.2%
Anthracite	0.7%	0.2%

SOURCE: State of New Jersey, Reference 10.

Table 6.2.7. NEW JERSEY SULFUR CONTENT LIMITATIONS BY FUEL OIL AND VISCOSITY

GRADES OF COMMERCIAL FUEL OIL	CLASSIFICATION BY SSU VISCOSITY @ 100°F	EFFECTIVE 5/1/68	EFFECTIVE 10/1/70	EFFECTIVE 10/1/71
No. 2 and lighter	Less than or equal to 45	0.3%	0.3%	0.2%
No. 4	Greater than 45 but less than 145	0.7%	0.4%	0.3%
No. 5, No. 6 and heavier	Equal to or greater than 145	1.0%	0.5%	0.3%

SOURCE: State of New Jersey, Reference 10.

Table 6.2.8 presents an overview of inspection points for fuel types and properties. Many of the properties shown should be subject to analysis by the laboratory of the enforcement agency. In doubtful or suspicious cases samples should be taken to the laboratory for analysis. Fuel properties will vary considerably among regions.

Enforcement officers should become familiar with the specific requirements in their regions. In regions where high sulfur, high ash fuels are the only economical fuels available, emphasis is usually given to air pollution control equipment, desulfurization of stack gases, boiler operation and design. In regions where lower sulfur and ash fuels are available, enforcement officers may participate in a program to promote and enforce fuel substitution. In cases of emission violations, they may be required to establish that the fuel used played a role in the violation. They should also become familiar with ASTM standards and procedures listed in Table 6.2.9.

1. COAL

Coal usually is classified by "rank," the degree of change from lignite to anthracite, as shown in Table 6.2.10. In addition to the chemical composition of coal, the physical property of caking (coking) is an important consideration in the ultimate use of stokers or other methods of firing. Caking refers to the remaining fixed carbon and ash melts after the volatiles have been distilled from the coal. To some degree caking takes place with all coal. The degree is variously described as strong caking, weak caking, or noncaking. Bituminous coal usually is caking coal and anthracite and most sub-bituminous coals are free burning or noncaking.

Table 6.2.8. OVERVIEW OF FUEL TYPES AND PROPERTIES AND SPECIFICATIONS PERTINENT TO AIR POLLUTION

COAL	OIL	GAS	OTHER
Type Bituminous Subbituminous Anthracite Semianthracite Lignite Properties Sulfur content pyritic, organic, sulfate Ash softening temperature Moisture content Fixed carbon Heating value Chlorine content Coal Sizing and Form Run-of-the-mine Slack coal Double screen Pulverized Caking coal Free burning coal	Type Distillate Grades #1 and #2 residential; commercial heating Grades #4 and #5 Blended Commercial and industrial Residual Grade #6, Bunker C, PS 400 Heavy oil-large boilers, public utility, industrial, commercial, diesel, marine Specifications Sulfur content Ash content Viscosity Flash point Gravity, API Pour point Water and sediment Heating value	Type Natural Coke oven Liquified Make-gas Waste-gas Constituents Methane, Ethane, etc. specific gravity (relative to air) Heat value	 Wood Refuse Oil shale Bagasse (sugar cane or beet residue) Coke breeze (coke fines) Char (fluidized bed) carbonized coal Petroleum coke Black liquor (paper pulp wastes)

Table 6.2.9. FUEL ANALYSIS, STANDARDS AND PROCEDURES REFERENCES

	Document
Specifications for Fuel Oils	ASTM D396
Moisture of Oil Determination ASTM Standard	ASTM D271, D1412-565
Coal Classification by Grade Standard	ASTM D389
Sampling and Analysis of Coal (percent of sulfur in coal) and Heat Content	ASTM D271-64
Sampling of Volatile Matter	ASTM D271-64, Appendix A
Gross Calorific Value of Solid Fuels by the Adiabatic Bomb Calorimeter	ASTM D2015-62T
Particulate Matter Emitted; Power Test Codes	ASME PTC27
Heat Content of Liquid Fuels	ASTM D240-64 ASTM D129-62 ASTM D270-65
Sampling Coal for Ash Content	ASTM D492-48
Preparing Coal Sample for Analysis	ASTM D2013-65$_T$
Mechanical Sampling of Coal	ASTM D2234-65$_T$
Grindability of Coal, for Pulverizing Equipment	ASTM D409
Test Code for Coal Pulverizers	ASTM D197
Classification of Coals by Rank	ASTM D388-38
Sieve Analysis Size Distribution	Bureau of Mines, Information Circular 7346 (1446)
Technical Manual on Single Retort Underfeed Stokers	JAPCA 9(3):145-146, November, 1959
Application of Over-Fire Jets to Prevent Smoke from Stationary Plants	Aid to Industry, 500-300. Bituminous Coal Research, Inc., Monroeville, Pa., 1957
Recommended Guide for the Control of Dust Emission - Combustion for Indirect Heat Exchangers	ASME Standard No. APS-1; 1966, Appendix B

Table 6.2.10. CLASSIFICATION OF COALS BY RANK

Class[a]	Group	Limits of fixed carbon or Btu mineral-matter-free basis	Requisite physical properties
I. Anthracite	1. Meta-anthracite	Dry FC[b] 98% or more (dry VM[c] 2% or less)	
	2. Anthracite	Dry FC 92% or more and less than 98% (dry VM 8% or less and more than 2%)	
	3. Semianthracite	Dry FC 86% or more and less than 92% (dry VM 14% or less and more than 8%)	Nonagglomerating[d]
II. Bituminous[e]	1. Low-volatile	Dry FC 78% or more and less than 86% (dry VM 22% or less and more than 14%)	
	2. Medium-volatile	Dry FC 69% or more and less than 78% (dry VM 31% or less and more than 22%)	
	3. High-volatile A	Dry FC less than 69% (dry VM more than 31%). Moist Btu[f] 14,000[g] or more	
	4. High-volatile B	Moist[f] Btu 13,000 or more and less than 14,000[g]	
	5. High-volatile C	Moist Btu 11,000 or more and less than 13,000[g]	Either agglomerating or nonweathering[h]
III. Subbituminous	1. Subbituminous A	Moist Btu 11,000 or more and less than 13,000[g]	Both weathering and nonagglomerating
	2. Subbituminous B	Moist Btu 9,500 or more and less than 11,000[g]	
	3. Subbituminous C	Moist Btu 8,300 or more and less than 9,500[g]	
IV. Lignitic	1. Lignite	Moist Btu less than 8,300	Consolidated
	2. Brown coal	Moist Btu less than 8,300	Unconsolidated

[a] Standard Specifications for Classification of Coals by Rank (ASTM D388-38, ASA M20.1-1938). This classification does not include a few coals that have unusual physical and chemical properties and that come within the limits of fixed carbon or Btu of the high-volatile bituminous and subbituminous ranks. All these coals either contain less than 48 percent dry mineral-matter-free fixed carbon or have more than 15,500 moist mineral-matter-free Btu.

[b] FC = fixed carbon.

[c] VM = volatile matter.

[d] If agglomerating, classify in the low-volatile group of the bituminous class.

[e] It is recognized that there may be noncaking varieties in each group of the bituminous class.

[f] Moist Btu refers to coal containing its natural moisture, but not including visible water on the surface of the coal.

[g] Coals having 69 percent or more fixed carbon on the dry mineral-matter-free basis shall be classified according to the fixed carbon, regardless of Btu.

[h] There are three varieties of coal in the high-volatile C bituminous coal group, viz., variety 1, agglomerating and nonweathering; variety 2, agglomerating and weathering; variety 3, nonagglomerating and nonweathering.

Source: W. S. Smith and C. W. Gruber, Reference 11.

Factors that are of particular importance in the emissions of air contaminants from the combustion of coal and fuel oil are sulfur content, volatile matter and ash content. The sulfur content includes organic sulfur, distributed in coal, and pyritic sulfur. Only the latter can be removed by washing or mechanical means. The ash content of fuels contributes to the emission of fly ash and other particulate emissions, and consists of inorganic materials such as metals and minerals including silica, iron, aluminum, calcium, vanadium, alkalies, calcium oxides, magnesium oxides and titanium oxide. The volatile matter consists of essentially the combustible material, exclusive of fixed carbon, including complex mixtures of hydrocarbons and organic materials which decompose to form smoke and organics during combustion. Variations in sulfur content and fuel properties in bituminous and anthracite coals are shown in Table 6.2.11. Other coal properties are described in Coal Preparation Plants, Chapter 7, Section 13.

2. FUEL OIL

Fuel oils of #1 and #2 grades, the distillate fuels, are usually used to heat homes and domestic hot water. #2 fuel oil is used in small apartment houses and industrial processes. The firing rate is usually not more than 20-25 gallons per hour.

Fuel oil of #4 grade, residual fuel oil, is fired in large apartments, small industrial plants and other commercial establishments up to 50 gallons per hour. Fuel oils #5, light and heavy, are used in installations burning more than 50 to 100 gallons per hour respectively. Fuel oil #5 possesses greater heating value. Fuel oil grade #6 is used in power generating stations, marine vessels and other large installations, and is fired at rates greater than 50 gallons per hour.

Table 6.2.11. VARIATIONS IN SULFUR CONTENT AND FUEL PROPERTIES LIKELY TO BE ENCOUNTERED

	BITUMINOUS	ANTHRACITE
Moisture, weight %	2-15	4-10
Volatile matter, weight %	14-40	4-8.5
Ash, weight %	4-15	7-20
Sulfur, weight %	0.5-4.5	0.4-0.8
Heating Valve, Btu/lb.	11,000-14,000	11,000-13,500

SOURCE: Smith and Gruber, Reference 11.

Important fuel oil specifications(12) of interest to the enforcement officer include:

Pour Point: The lowest temperature at which oil will barely flow. Pour point is measured by chilling a sample of fuel oil in a glass jar at a constant rate. It is specified as 5°F above the exact temperature at which the oil will not move when the test jar is held horizontally for five seconds. The pour point may be important in frigid climates as an indicator of whether or not fuel preheating is required.

Cloud Point: The temperature at which a cloud or haze of wax crystals appears in the cooled sample, applied only to transparent oils. The cloud point indicates whether filters and lines will be clogged due to crystal accumulation at lower temperatures.

Saybolt Viscosity: The source of the resistance of the fuel oil to flow or shear. Viscosity is a function of temperature. SSU (Saybolt Seconds Universal) is the number of seconds it takes 60 cubic centimeters of an oil to flow through the standard orifice of a Saybolt Universal Viscometer at 100°F.

Gravity: Gravity is an indirect measure of heat content, and is measured by means of a hydrometer, in relation to the density of water. Heat content is related to degrees of API gravity, which can be established from standard API tables. For example, a fuel of API gravity of 33 possesses a heat content of 140,000 Btu per gallon.

The sulfur content of No. 1 distillate will vary from .04-.124, and of No. 2 distillate from .104-.307. The sulfur content in Grade 6, residual oils will range from 0.9 to 3.2% by weight.

3. GASEOUS FUELS

Natural gas consists of primarily methane and ethane, although small amounts of sulfur compounds are usually added to distribution lines (about .15 grain calculated as sulfur per 100 SCF) to impart a detectable odor to the fuel. The primary problem from natural gas burning is CO and NO_x emissions.

4. FUEL SAMPLING

Determinations of emission rates, as well as compliance with fuel limitations, are based on the sampling and analysis of fuels (see Table 6.2.9). The inspector obtains a sample of the fuel which is representative of the fuel stored or fired, seasonal or other cyclic operations, or of operations related to an actual or suspected violation of visible emissions. Also, samples may be taken from the consumer, supplier, distributor or the mine. The inspector may:

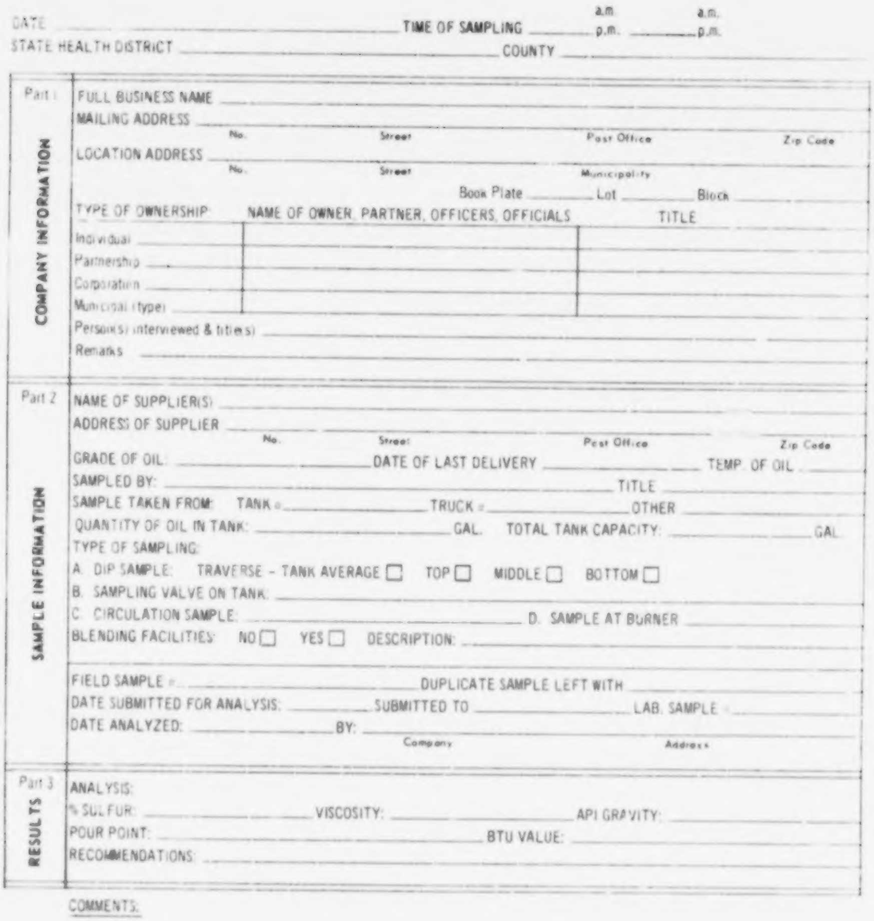
1. Conduct fuel inventories of all suppliers in a region.
2. Determine the source of the fuel, including the producing district.
3. Establish the representative fuel properties and fuel preparation methods for each producing district by coal rank and type.
4. Take samples and forward them for laboratory analysis to establish or verify fuel properties.
5. Match fuel properties with commercial names.

Coal can be sampled in 10 pound containers, and oil in pint, quart or gallon plastic or tin containers. A sample coal shovel is used, for example, to sample coal from a chute feeding a stoker. Samples are taken at regular intervals and placed on a tarp (usually 4' x 6') until approximately 100 pounds of coal are collected. The tarp is folded over the coal and the coal shaken. From this sample, approximately ten pounds of coal are taken in a 10 pound bucket to the laboratory for analysis. Samples of fuel oil can be taken from the fuel or service line, or the storage tank with an "oil thief." A typical fuel survey form is shown in Figure 6.2.3.

D. TYPES OF FUEL-BURNING FUNCTIONS

The fuel-burning function relates to the purpose of the fuel-burning and is important from the standpoint of the number and types of users, and degree of control the user can exercise as an individual and as a class over his operation to control emission rates.

Each fuel user class presents different problems which must be appropriately treated from an inspection and enforcement standpoint. Residential space-heating usually will be treated as an area source, handled primarily through region-wide fuel substitution and special equipment prohibitions or as single code violations. A large single-point source, such as a power plant, may be attacked from the standpoint of fuel supply, burner design, power plant design and air pollution control equipment. The specificity and breakdown of fuel-burning functions may differ among enforcement agencies according to the emphasis with which any class of fuel-burning source is to be controlled. A general scheme for fuel-burning operations, given by building or plant categories is shown in Figure 6.2.4.



DATE ______ TIME OF SAMPLING ______ a.m. p.m. ______ a.m. p.m.
STATE HEALTH DISTRICT ______ COUNTY ______

COMPANY INFORMATION

Part 1

FULL BUSINESS NAME ______
MAILING ADDRESS ______
No. Street Post Office Zip Code
LOCATION ADDRESS ______
No. Street Municipality
Book Plate ______ Lot ______ Block ______

TYPE OF OWNERSHIP	NAME OF OWNER, PARTNER, OFFICERS, OFFICIALS	TITLE
Individual		
Partnership		
Corporation		
Municipal (type)		

Person(s) interviewed & title(s) ______
Remarks ______

SAMPLE INFORMATION

Part 2

NAME OF SUPPLIER(S) ______
ADDRESS OF SUPPLIER ______
No. Street Post Office Zip Code
GRADE OF OIL: ______ DATE OF LAST DELIVERY ______ TEMP. OF OIL ______
SAMPLED BY: ______ TITLE ______
SAMPLE TAKEN FROM: TANK # ______ TRUCK # ______ OTHER ______
QUANTITY OF OIL IN TANK: ______ GAL. TOTAL TANK CAPACITY: ______ GAL.
TYPE OF SAMPLING:
A. DIP SAMPLE: TRAVERSE – TANK AVERAGE ☐ TOP ☐ MIDDLE ☐ BOTTOM ☐
B. SAMPLING VALVE ON TANK: ______
C. CIRCULATION SAMPLE: ______ D. SAMPLE AT BURNER ______
BLENDING FACILITIES: NO ☐ YES ☐ DESCRIPTION: ______

FIELD SAMPLE # ______ DUPLICATE SAMPLE LEFT WITH ______
DATE SUBMITTED FOR ANALYSIS: ______ SUBMITTED TO ______ LAB. SAMPLE # ______
DATE ANALYZED: ______ BY: ______
Company Address

RESULTS

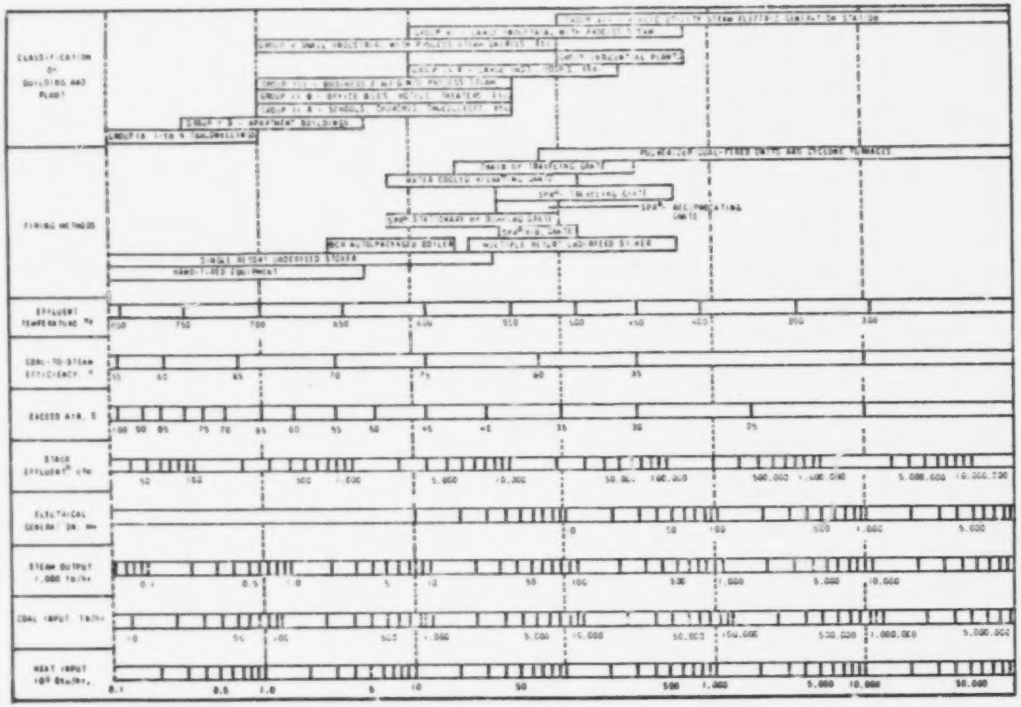
Part 3

ANALYSIS:
% SULFUR: ______ VISCOSITY: ______ API GRAVITY: ______
POUR POINT: ______ BTU VALUE: ______
RECOMMENDATIONS: ______

COMMENTS:

Figure 6.2.3. A TYPICAL FUEL SURVEY FORM

SOURCE: STATE OF NEW JERSEY, REFERENCE 13.



SPR^a- SPREADER STOKER

^b At 60 °F, 1 atmosphere and indicated excess air

Figure 6.2.4. SUMMARY OF CHARACTERISTICS OF COAL FIRING EQUIPMENT

SOURCE: SMITH AND GRUBER, REFERENCE 11.

The fuel-burning operation may be independent (stand alone) or on-line with other processes. Generally speaking, when the fuel-burning operation is used to provide space heating or electrical power, the inspector is not directly concerned with steam distribution or electrical power generation and distribution equipment, except possibly to establish load conditions and peaks imposed upon the combustion equipment. When the fuel-burning equipment is used to provide steam or heat to other processes which may emit important contaminants, or if emissions from other processes are vented to the firebox or to the stack of the boiler, then the inspector must inventory or note this equipment and evaluate its air pollution potential. The inspector should show the flow of fuel, air, and process material to the system, together with a description of the ventilation system, including blower size and horsepower, ash removal rate, points of air pollution emission, air pollution control equipment, and stack characteristics.

E. SIZE OF FUEL-BURNING FUNCTIONS

The size of the fuel-burning operation is important from the standpoint of the fuel firing rates, the size of the combustion chamber, and the rate of thermal energy produced since these parameters are related to emission rates. Small fuel-burning operations tend to be less efficient than larger installations per pound of fuel burned. State and local air pollution control regulations tend to define fuel-burning equipment by size, and inspection programs are designed accordingly. Permit fees are also related to size of equipment.

The size of the operation may be rated by Btu per hour of heat input, fuel firing rates, pounds of steam per hour produced, boiler horsepower, or electrical energy. Most legislation deals with Btu per hour heat input which can be related to fuel firing rates, as noted in Table 6.2.12, and to contaminant emissions. The horsepower rating is commonly found on the combustion equipment and is related to the pounds of steam produced per hour. A 1,000 HP boiler is equivalent to about 34,500 pounds of steam production per hour or 2,500 pounds of oil fired per hour. The Btu value may be computed from knowledge of the heat content of the fuel. The average heat content of oil, for example, may be 18,300 Btu per pound burned. A 1,000 HP boiler installation may produce about 45-46 million (46×10^6) Btu/hour.

The Btu input rating obtained from the fuel firing rates is more increasingly relied upon as a function of "size," than is boiler horsepower or pounds of steam. The Btu rating tends to be most related to the total pollutants emitted. The boiler horsepower rating, stamped on boilers, is often unreliable as an indicator of capacity. For permit applications, emission inventories or source registration, the Btu/hour input estimate is usually taken as the larger of either the boiler rating or the operational practice.

Figure 6.2.4 relates size of operation and fuel-burning function to Btu heat input, steam output and other combustion ratings. Equipment subject to inspection is likely to be in the 1×10^6 Btu/hour and greater classifications, depending on the air pollution problems and regulations in effect in the air quality region.

The heat input value is used in a number of ways of interest to the inspector. For example, emission factors may be related on a graduated

Table 6.2.12. CONVERSION OF FUEL TO HEAT EQUIVALENCY, AVERAGE VALUES

26×10^6 Btu in 1 ton coal

1×10^3 Btu in 1 cu. ft. natural gas

136×10^3 Btu in 1 gal. No. 1 oil

139×10^3 Btu in 1 gal. No. 2 oil

144×10^3 Btu in 1 gal. No. 4 oil

148×10^3 Btu in 1 gal. No. 5 oil

151×10^3 Btu in 1 gal. No. 6 oil basis to the heat in the fuel burned. Proposed regulations may prohibit the use of certain fuels such as coal or residual oils in units with less than a specific heat input, e.g., 5 million Btu/hr.

The heat input value may also be used as a criteria for source registration, e.g., all units burning coal or wood with heat input values of 350,000 Btu/hour or greater (approximately 28 pounds of coal per hour fuel use rate) must be registered. Permit or other fees may also be assessed on the basis of heat input.

The type of equipment the inspector will physically inspect is also related to size. Factors include the type and construction of the firebox, heat exchanger and method of firing. In general, small boilers or heaters (residential and some institutional) are likely to be of the water-tube type in which the water flows through tubes which are heated by combustion air. Intermediate types of boilers may be of fire-tube, scotch marine, or cast-iron sectional construction as shown in Figures 6.2.5, 6.2.6 and 6.2.7. Large steam generating stations or recovery furnaces (see Kraft Mills, Chapter 7) are based on water tube or water wall construction. Fireboxes may be of refractory construction in intermediate units, whereas small and large-scale units are of metal construction.

The size of the fuel-burning operation also involves considerations of scale and design which affect the types and rates at which contaminants are emitted. Emissions of oxides of nitrogen and sulfur trioxide are a function of size as well as other considerations treated in this section.

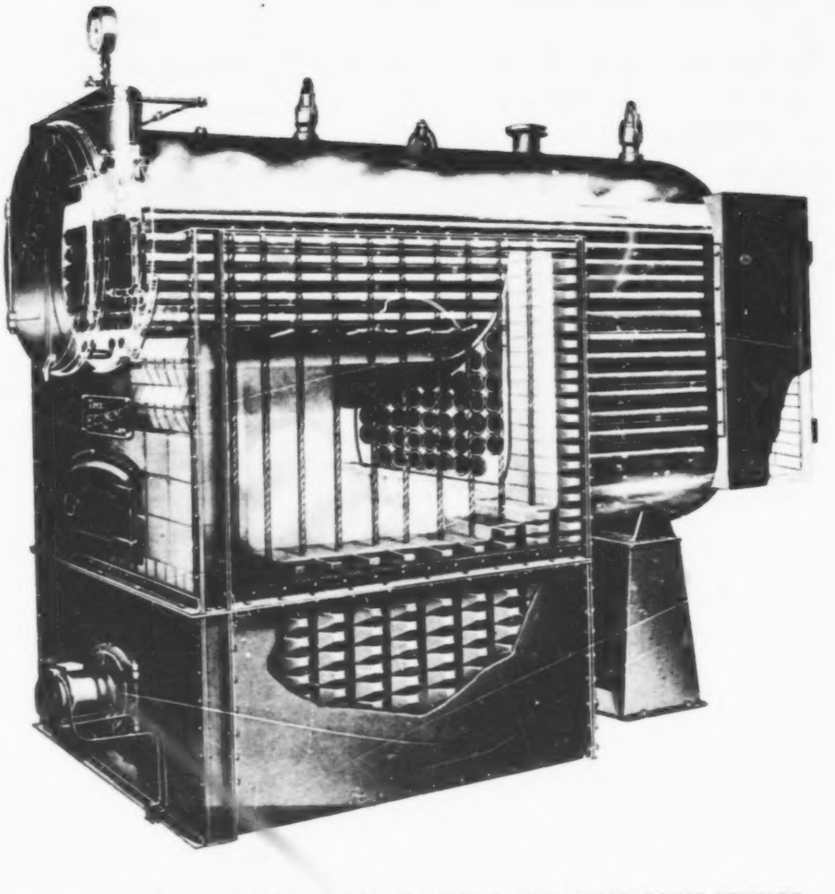


Figure 6.2.5. A FIRE-TUBE BOILER WITH A REFRACTORY-LINED FIREBOX
(ERIE, CITY IRON WORKS, ERIE, PA.)

SOURCE: WALSH, REFERENCE 3.

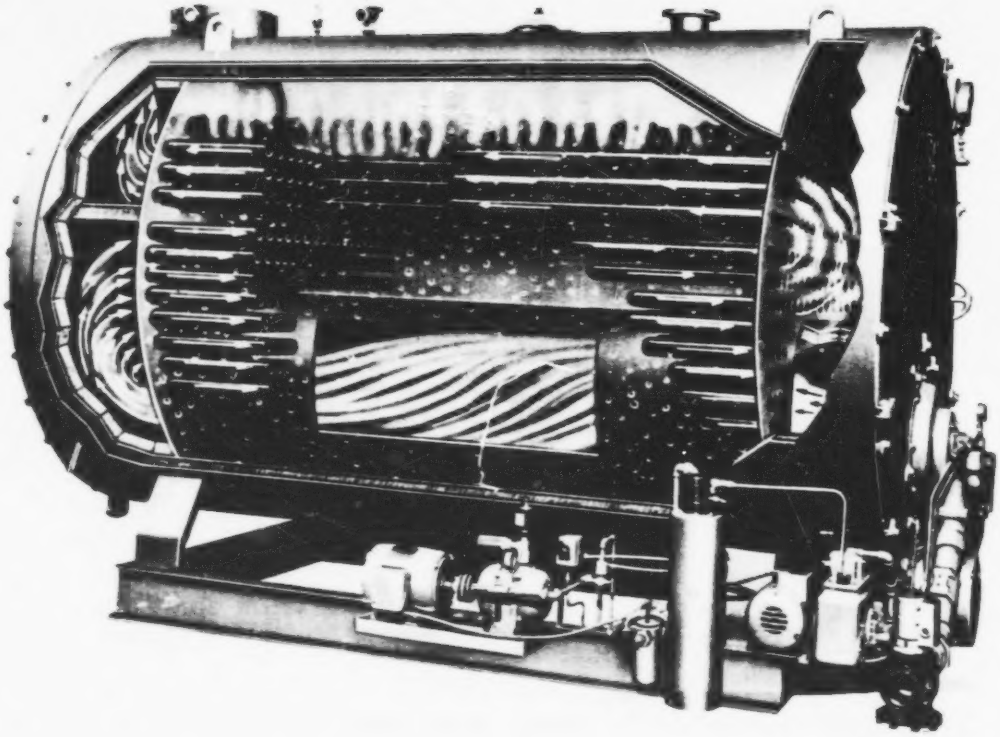


Figure 6.2.6. A THREE-PASS, SCOTCH-MARINE BOILER (RAY BURNER CO., BOILER DIVISION, SAN FRANCISCO, CA.)

SOURCE: WALSH, REFERENCE 3.

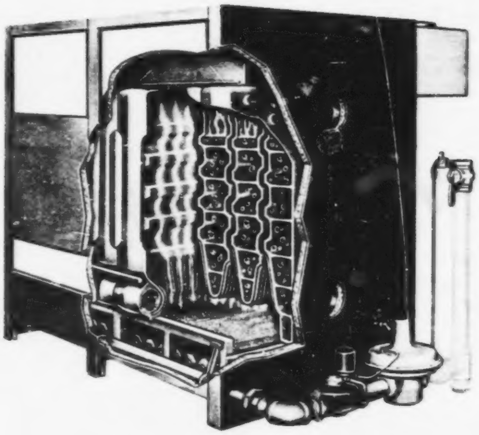


Figure 6.2.7. A CAST IRON SECTIONAL BOILER (CRANE CO., JOHNSTOWN, PA.)

SOURCE: WALSH, REFERENCE 3.

F. INSPECTION POINTS

Many of the inspections to be conducted in the field will involve fuel-burning installations. Field operations functions will include:

1. Enforcement of all regulations affecting the use of fuels and the installation and operation of fuel-burning equipment. Typical enforceable regulations are shown in Table 6.2.4.*

2. Establishing the causes of excessive emissions and public nuisances.

3. Inventorying fuel-burning equipment in buildings and plants.

4. Assistance in source testing and emission inventories.

5. Collection or verification of information for source registration purposes.

6. Assistance in the administration of a permit system.

7. Checking progress in meeting compliance plan schedules.

8. Participation in fuel-use or fuel marketing surveys.

9. Responding to questions concerning the completion of source registration questionnaires and application forms by respondents.

---

*Attainable emission limits are listed in Table 1.2, Chapter 1. Rules recommended under the Clean Air Act are described in Reference 14.

The inspection points and the type of information the inspector collects will depend on the type and purpose of his investigation. An inspection involving equipment or emission inventories, permit system checks, or source registration follow-ups will require:

1. Identification Data. The identification and listing of all equipment and principal equipment components at the facility capable of emitting air pollutants.

2. Descriptive Data. The acquisition of descriptive information on the equipment to establish or verify the principal design features, such that gross alteration to the equipment above that found on previous inspection reports and applications can be determined. Descriptive information includes, for example, the number and type of boilers, type and capacity of air pollution control equipment, the number, types and placement of burners, the type and horsepower of combustion air blowers, the breeching of boilers in series, etc.

3. Operational Practices Data.. These include established, i.e., ongoing practices relating to the type and grade of fuels normally used, standby equipment utilization, method of ignition and control, ash handling and soot blowing, quantities of fuel and materials processed, operating schedules, and operating conditions as may be noted from process control monitors.

Incident investigations concern inspections that are made pursuant to a visible violation or a public nuisance. This type of investigation requires that the enforcement officer have knowledge of the installation, as may be gained from previous inventory inspections, and intensive inspection of operational practices as close to the time of the incident or the violation as possible.

Figure 6.2.8 is a simple correlation of the fuel burning-parameters which have the greatest impact on the quantities of contaminants emitted by class. In practice, the enforcement officer will be most concerned with visible emissions--smoke, SO_3 and particulate fall-out nuisances. He should also be prepared to report on the parameters which produce non-visible emissions such as CO, NO_x, organics and submicron particulates, even though he may not always be able to quantitatively estimate actual emission rates. Such information may lead to a source test request. Table 6.2.13 correlates the likely inspection points of interest with types of inspections and required information. Specific inspection points relating to specific types and components of fuel-burning equipment are treated in the following parts of this section.

In conducting the physical inspection of fuel-burning installations, the field enforcement officer should be aware that the emissions of a variety of air contaminants are sensitively related to the specific characteristics of fuel firing systems in several ways. First, the firing system comprises the most variable feature of boiler operations. Excessive emissions of smoke, particulates and carbon monoxide are related to burner or stoker feed rates, adjustment, wear and level of maintenance. The variability of the operation further increases with the number of burners employed and with fuel properties. Second, the design of the firebox and placement of burners affect SO_3 and NO_x emissions.

SO_3 emissions, for example, depend largely on the size and temperature of the firebox. Crumley and Fletcher(15) found that:

- SO_3 formation increases as flame temperatures are increased up to about 3150°F.
- Above 3150°F SO_3 formation does not increase, that is, the SO_3/SO_2 rate remains constant.
- When flame temperatures are held constant, SO_3 formation decreases as the excess air rate is reduced.
- SO_3 formation decreases with coarser atomization, possibly due to lower resultant flame temperatures

CONTAMINANT	FUEL-BURNING FACTOR
SO_2 Ash (particulates)	Fuel Type, Grade, Size, Rank, Composition
Smoke, particulates CO Aldehydes Organic Acids	Fuel Burner Design and Operation Air Fuel ratio Atomizing Mixing and Turbulence Time Interval
SO_3 - Visible Plume	Power Plant Size Firebox Temperature Excess Oxygen Oxygen Concentration Oxidation Catalysts in Tube Deposits and Particulates
NO_x	Power Plant Size Boiler/Furnace/Firebox Design Firing Rates Firing System Design Flame Temperature Residence Time of Combustion gases in High Temperature Zone Excess Oxygen

Figure 6.2.8. RELATION OF MAJOR POLLUTANTS TO PRINCIPAL DESIGN AND OPERATIONAL VARIABLES

Table 6.2.13 EXAMPLES OF FUEL-BURNING EQUIPMENT INSPECTION POINTS AS RELATED TO TYPE OF INSPECTION

COMBUSTION SYSTEM COMPONENTS	INVENTORY INSPECTION POINTS			INCIDENT INVESTIGATION
	IDENTIFICATION DATA	DESCRIPTIVE DATA	OPERATIONAL PRACTICES DATA	VIOLATION & NUISANCE INVESTIGATION: SMOKE PARTICULATES, SPECIFIC CONTAMINANTS
Boiler & Supporting Equipment.	Boiler type, (fire tube, water tube, etc.). Boiler H.P., Btu rating. Make and model and serial number.	Instruments/controls employed: air/steam, [illegible] / steam, combustion recorders, smoke indicators, alarms etc. Stack height & diameter.	Extent of equipment supervision & operation. Operation & use of smoke alarm equipment.	Ringelmann/Opacity from stack or other source. Readings of oxygen, CO_2, fuel & other instruments. Particulate, soiling, fallout indications.
Fuel used.	Fuel Type.	Fuel Type.	Grade, rank, analysis, size; average and peak firing rates.	Grade, rank, analysis, firing rates, fuel oil viscosity, preheater temperature.
Stoker and/or Burner.	Burner type. Combination/standby equipment.	Placement of burners (corner, front, vertical). Single vs. dual stage. Clearance of burners in firebox (feet). Overfire air controls. Provision for fuel oil preheaters (electric, steam). Smoke Reading Equipment.	Conditions of burners and/or stoker equipment. Use of standby and combination equipment. Ignition method and conditions. Coal & ash thickness on stoker grates. Distribution of coal sizes on grate. Fuel preparation procedure.	Appearance of flame. Flame clearance (same as operational practices data).
Firebox.		Firebox dimensions. Type of refractory Combustion air provision (natural, forced, induced).	Refractory repair. Firebox temperatures. Flame temperatures.	Condition of refractory. Primary and secondary air rates. Damper settings and compartment pressure.
Ash and Soot Handling		Location of ash pit and provisions for ash removal. Soot blowing method. Number, type (air/steam).	Ash handling, removal rate and disposal. Ash analysis. Soot blowing schedule. Tube washing procedures.	Ash accumulation in pits. Ash quenching and watering. Dirt in fire tubes or vent system.

NO_x concentrations vary with flame temperature, firebox oxygen concentration and firebox and burner design, for example:

- At 3,000°F firebox temperature concentrations are well over 1,000 ppm at 1% oxygen.
- Calculated flame temperatures are in excess of 4,000°F at 10% excess air (2% oxygen) for both oil and gas firing when air is preheated at 600°F.
- NO_x emissions tend to be 35 to 50% higher during oil firing than gas firing.

NO_x emissions can be reduced by employment of a two stage combustion(3) design in which

- Only 90 to 95% of theoretical combustion air is injected at the burner.
- Remaining air is introduced a few feet downstream of the burner to complete combustion over a somewhat larger zone.
- Normal excess air rate is maintained.

In some installations NO_x emissions may be reduced by modifying the combustion control system to give a more precise method for proportioning fuel and air. One method is supplying all of the fuel through the bottom of a number of rows of burners while maintaining normal air flow to all burners. The delayed introduction of excess air tends to reduce NO_x concentrations in flue gases by 40 to 50%. Also, tangential, (corner fired) burners can result in substantially less NO_x emissions than front-fired units.

Other approaches used are aimed at reducing flame temperature or the time the combustion gases are exposed to high temperature. These include increased flue gas circulation, varying air flow to various burner levels and injecting steam at the burners.

The relationship of fuel properties to combustion equipment is further illustrated in the following tables: Coal Characteristics Relative to Method of Firing, Table 6.2.14; and General Uses of Bituminous Coal Sizes in Relation to Type of Coal Burning Equipment, Table 6.2.15.

The text below summarizes background information on the operation and inspection of the principal types of fuel firing systems that are likely to be encountered in the field. Actual inspection points will depend on the inspection and the type of equipment involved. Some of the first-hand information the field enforcement officer collects such as the appearance of the flame, condition of refractories, type of coal and apparent thickness of the fuel bed may relate directly to an air pollution incident. Other information such as type of slag tap furnace, fineness of coal, or excess air may be needed for inventory or source registration follow-up inspections, and may be collected by the field enforcement officer to permit subsequent retrieval and evaluation by the engineering staff of the enforcement agency. This information may be acquired by direct observation, reading of instrument gauges and interviews with the air pollution or technical staff of the plant. Specific inspection procedures will depend on the policies of the enforcement agency involved.

I. Solid Fuel-Burning Systems--Inspection Points and Operating Guides

In general coal-firing systems provide for the feeding of raw fuel, the ignition of the fuel and the removal of ash. Systems generally vary in the direction and method by which raw coal reaches the fuel bed, and the flow of primary air in relation to the movement of the bed. The firing method will depend on the type of coal available and used.

a. Stokers (Commercial, Institutional and Industrial)

(1) Function and Types

Stokers are designed to produce steam in small and moderate size boilers, and are generally limited to 400,000 lbs. steam/hour. They fall into the following classifications:

Table 6.2.14. COAL CHARACTERISTICS RELATIVE TO METHOD OF FIRING

METHOD OF FIRING	STOKER	PULVERIZED COAL	CYCLONE FURNACE
Max Total Moisture *	15-20	15	20
Min Volatile Matter (dry basis), %	15	15	15
Max Total Ash (dry basis), %	20		25
Max Sulfur (as fired), %	5	--	--
Max Ash-Softening Temp, F	--	--	2400

---

* These limits may be exceeded for lower rank, higher inherent-moisture-content coals, i.e., subbituminous and lignite.

Source: Babcock and Wilcox Company, Reference 1.

Table 6.2.15. GENERAL USES OF SEVERAL BITUMINOUS COAL SIZES

Type	Most common use
5 lump	Hand-firing, domestic and industrial
5 x 2 egg	Domestic hand-firing and gas producers
2 x 1 1/4 nut	Domestic hand-firing, industrial stokers, and gas producers
1-1/4 x 3/4 stoker	Domestic and small industrial stokers
1-1/4 x 5/16 stoker	Domestic and small industrial stokers
3/4 x 3/8 stoker	Domestic and small industrial stokers
3/4 x 0 slack	Industrial stokers and pulverizers
5/8 x 0 slack	Particularly suited to pulverizers
1/2 x 0 slack	Particularly suited to pulverizers
1/4 x 0 slack	Particularly suited to pulverizers
1-1/4 x 0 nut and slack	Industrial stokers
2 x 0 nut and slack	Industrial stokers

Source: W. S. Smith and C. W. Gruber, Reference 11.

- Overfeed--In this equipment burning gases rise through fresh fuel resulting in rapid devolatization of the new fuel in a zone deficient in oxygen. These designs together with hand-fired equipment inherently smoke and are disappearing from use.

- Underfeed--These units include single retort, multiple retort; screw fed or ram fed. Air and fresh fuel flow concurrently, usually upward. The zone of ignition is near the point of maximum evolution of combustible gases, and is supplied with ample air and adequate mixing to promote complete combustion. These designs tend to be smoke-free, but substantial quantities of fly ash may be emitted because of the high velocity jets of escaping gas. Dust collectors may be required. This type of design is better suited for caking coals. Screw fed units burn 60-1200 lbs. coal/hour; ram fed, 400-3500 lbs. coal/hour. Multiple retort boilers produce 20,000 to 500,000 lbs. steam/hour with burning rates up to 600,000 Btu/sq. ft. of grate area (see Figures 6.2.9 and 6.2.10).

- Spreader Stokers--Employ a mechanical spreader or jets of steam or air to throw solid fuel into furnaces where it falls on a stationary or traveling grate (suspension firing, see Figure 6.2.11). Control of smoke is good, but overfire jets are essential, and high efficiency collectors for particulates are required. A rotating flipper mechanism throws the fuel onto the furnace grate. The fuel thus burns partly in suspension and partly on grates. Spreader stokers have a capacity of 6-500 X 10^6 Btu/hour.

- Traveling Grate and Chain Grate (Figure 6.2.12) and Vibrating Grate (Figure 6.2.13). The stoker carries fuel from a hopper by a moving, endless grate system, through a gate into and to the rear of the furnace. Ash is continuously discharged. The vibrating grate includes a high speed vibrating mechanism on a time cycle control for homogenous distribution of coal sizes. Traveling and chain grates have capacities of 20 to 300 x 10^6 Btu/hour; vibrating grate, 350,000 - 500,000 Btu/sq. ft. hour.

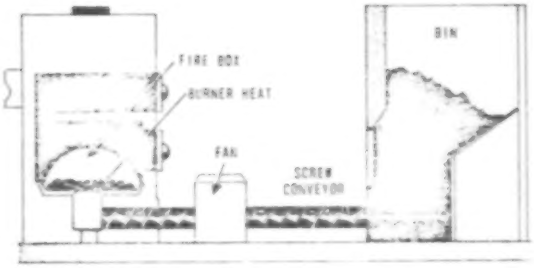

FIRE BOX
BURNER HEAT
FAN
SCREW CONVEYOR
BIN

Figure 6.2.9. RESIDENTIAL UNDERFEED STOKER

SOURCE: NAPCA, REFERENCE 16.

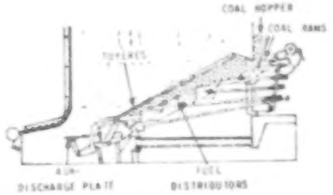

COAL HOPPER
COAL RAMS
TUYERES
ASH DISCHARGE PLATE
FUEL DISTRIBUTORS

Figure 6.2.10. MULTIPLE-RETORT UNDERFEED STOKER

SOURCE: NAPCA, REFERENCE 16.

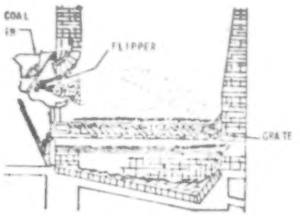

COAL IN
FLIPPER
GRATE

Figure 6.2.11. SPREADER STOKER-FIRED FURNACE

SOURCE: NAPCA, REFERENCE 16.

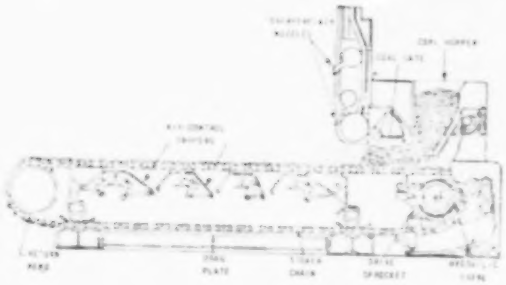

OVERFIRE-AIR NOZZLES
COAL HOPPER
COAL GATE
AIR-CONTROL DAMPERS
RETURN BEND
DRAG PLATE
STOKER CHAIN
DRIVE SPROCKET

Figure 6.2.12. B & W JET-IGNITION CHAIN-GRATE STOKER

SOURCE: NAPCA, REFERENCE 16.

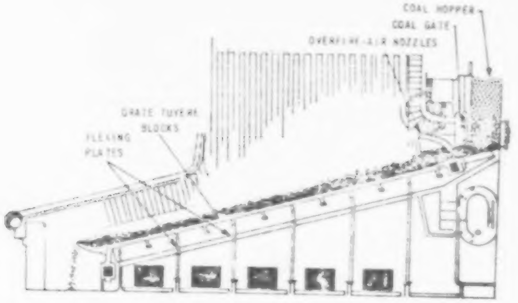

COAL HOPPER
COAL GATE
OVERFIRE-AIR NOZZLES
GRATE TUYERE BLOCKS
FLEXING PLATES

Figure 6.2.13. VIBRATING-GRATE STOKER FURNACE

SOURCE: NAPCA, REFERENCE 16.

(2) Factors affecting Emissions. Spreader stokers tend to have high fly ash carryover with high burning rates, and tend to smoke at low burning rates. Otherwise, overall factors affecting emissions from stoker equipment are similar and include:

- Overall fuel properties, discussed in Part C
- Distribution of coal sizes on grate.
- Fuel bed thickness on grates.
- Grate speed.
- Air distribution and compartment pressure.
- Ash discharge and removal procedures.

These factors are discussed below.

(3) Fuels and Fuel Preparation:

- Almost any coal--including anthracite, coke breeze, lignite--can be fired. Hogged wood, bark, and bagasse can also be fired.
- Caking coals should be avoided. Coal can be preconditioned by adding moisture for improved burnout of carbon and removal of 1/4" fines for better air flow through grate, but moisture in high sulfur fuels can cause corrosion of equipment. Caking coals may be dried or weathered to achieve the swelling or thickening desired.
- Bituminous coal should pass through 1" ring, and 60% through 1/4" screen. Anthracite #2 coal should pass through 5/16" - 3/16" screen; #5 through 3/64". Coke breeze should pass through 3/8", less than 20% through 1/32" screen.
- Auxillary gas and oil firing systems are frequently used with chain grate stokers.

- Underfeed stokers can fire a wide range of coal.
  Note:

  - Horizontal feed type is good for free-burning coal sizes--1 1/4", zero nut, pea or slack in equal proportions are most desirable.

  - Anthracite can be burned separately or mixed with bituminous coal.

  - Stationary grates can burn coal with low ash fusion temperatures without clinker problems. Agitating type grates can burn coal with high caking tendencies.

- Coal hoppers should not be allowed to run empty, particularly with spreader stokers.

(4) Stoker Conditions:

Traveling, Chain Grate, Vibrating Grate, Spreader

- Coal sizing should be distributed across width of stoker to prevent overheating of grates. Use of traversing coal spout is desirable. Strips or areas of coarse coal tend to mat.

- Coal gate opening controls fuel-bed thickness, and is usually adjusted by hand.

- Fuel bed thickness for bituminous coal should be about 5" to 7"; for anthracite, 3 1/2" to 5".

- Grate speed should be maintained so that ignition is maintained at front end of stoker, the fuel should not burn back to the raw coal gate.

- In spreader stokers, the thickness of the ash on the grate at point of dumping governs speed of grate travel Bituminous ash thickness should be about 3" to 5". Spreader controls are used to maintain proper fuel distribution over active grate area.

- Grates should be maintained in good condition: broken grates should be replaced.

- Traveling and chain grate equipment may be able to operate smokelessly from 10% to full load.

- With rapidly fluctuating loads, fuel bed is carried longer; the rate of burning is reduced in second and third compartments by lowering blast pressure and increasing pressure slightly in rear compartments.

- If oil or gas is used, flame should not impinge on furnace walls or grate surfaces. 4" - 5" layer of ash should be maintained on chain grates. Firebricks or false refractory floors should be used if changeover is for a long period of time.

Underfeed

- Mechanical ram feeds coal to pusher blocks that distribute coal in firebox. Note:

  - Separate overfire air systems.

  - Grates must be kept cool. Hot spots can be noted through wind box doors.

(5) Combustion Air and Firebox:

- All overfeed units have zoned controlled forced draft undergrate provisions with automatic combustion control systems, including individual sectionalized zone dampers.

- Responsive combustion control systems are particularly required with spreader stokers.

- Overfire air is frequently used on all systems to burn volatiles.

- Water cooling may be found in newer furnaces.

- Settings and seals on doors and ports should be used and kept in good condition to prevent furnace air infiltration.

- Forced draft air pressure and grate speed are regulated by steam pressure when automatic combustion controls are used. Distribution of air in compartments under stoker grate is adjusted manually. Boiler meters (CO_2 recorders) will indicate pressures in various compartments by weight of air. Highest air pressures are maintained in middle compartments, for most furnaces. Settings of pressure in compartments are related to type of coal burned, e.g.,

  - Bituminous coal--highest pressure in second compartment 1" - 3" water, depending on load and fuel bed thickness; pressure in first compartment, 30 percent; pressure in third, 60%. Pressure tapers to zero in last compartment.

  - Small anthracite or coke breeze--air pressure in first compartment is blanked off with dead plate and should not exceed .1" of water. Pressures in succeeding compartments are gradually increased with the highest in the next to the last compartment.

- Spreader stokers should not be operated for long periods with one section clean and another dirty. This impairs the uniformity of air distribution. Excess air should be in range of 25 to 40% (see Table 6.2.3).

- Combustion control system--air flow steam-flow proportions air and fuel more accurately than does simple positioning type of system (coal feed and air flow rates reduce with drop in load).

- Multiple retort underfeed stoker--consists of several indirect retorts side by side; tuyeres are located between each retort

  - Forced air system is zoned beneath grates by air dampers.

  - Combustion controls are fully modulating.

  - Water cooled walls are used in larger systems.

  - Air ports may be blocked by slag and should be checked.

(6) Ash Handling:

- Ash may be raked by hand or removed by a water sluice, drag conveyor or jump pump, or dumped into a disposal car and quenched.

- Ashes should be wet down when removed.

- Underfeed Units--ash is continuously discharged to pit by side-dump grates
  - Water sprays in ash pit are sometimes used to cool refuse immediately after burning.
  - Frequency of ash cleanings should be geared to prevention of clinkering.
  - Uniform air fuel relation must be maintained over entire stoker area.
  - Air leaks through setting should be prevented.
  - Ash should be kept on stoker grates as insulation and protection against overheating.
  - Excess siftings should not be permitted to build-up in stoker wind boxes.

b. Pulverized Fuel-Burning Equipment

(1) Function and Types

- Pulverized Coal-Firing Equipment--Coal is dried and ground into powder and fed to burners in a manner similar to oil-burning equipment. Pulverized coal-firing and cyclone furnaces represent the principal firing methods for large coal-firing steam generating stations. Pulverized coal-firing equipment is used in steam generation, cement, metallurgical processes including copper and nickel ore smelting. Capacities run from 200,000 to several million pounds steam/hour.

  Various types of pulverized coal-firing equipment are important from the standpoints of gathering identifying and descriptive information for inventory and registration inspections and emission potentials. These include the bin system in which coal is ground and then conveyed to storage by a pneumatic transport system to the burners of the furnace (Figure 6.2.14) and the Direct-Firing system where the pulverizer is integral to the combustion system (Figure 6.2.15).

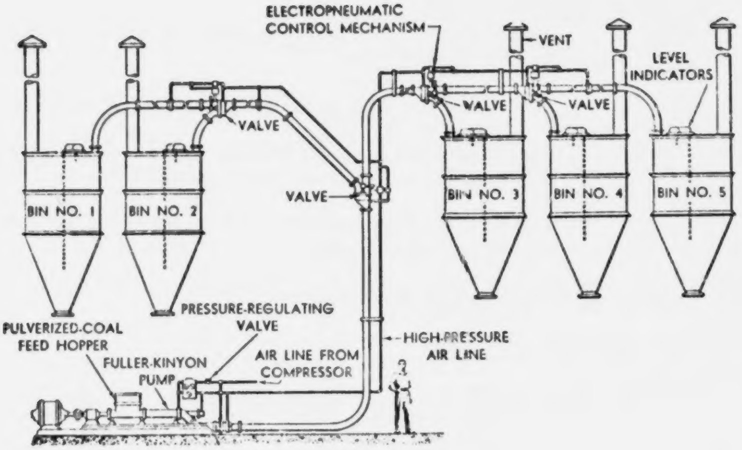

ELECTROPNEUMATIC CONTROL MECHANISM
VENT
LEVEL INDICATORS
VALVE
VALVE
VALVE
VALVE
BIN NO. 1
BIN NO. 2
BIN NO. 3
BIN NO. 4
BIN NO. 5
PRESSURE-REGULATING VALVE
PULVERIZED-COAL FEED HOPPER
FULLER-KINYON PUMP
AIR LINE FROM COMPRESSOR
HIGH-PRESSURE AIR LINE

Figure 6.2.14. PULVERIZED-COAL BIN SYSTEM. PNEUMATIC TRANSPORT SYSTEM FOR CONVEYING PULVERIZED COAL. CAPACITY 1 to 100 TONS PER HOUR

SOURCE: BABCOCK AND WILCOX, REFERENCE 1.

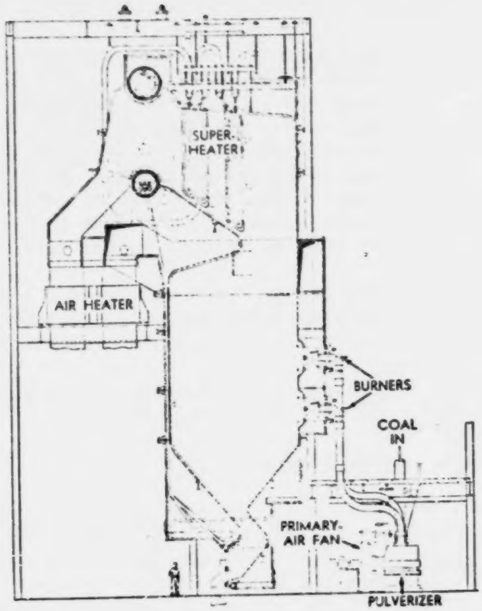

SUPER-HEATER
AIR HEATER
BURNERS
COAL IN
PRIMARY-AIR FAN
PULVERIZER

Figure 6.2.15. STIRLING TWO-DRUM BOILER (B&W).
INDIRECT-FIRED WITH PULVERIZED COAL
COMPONENTS OF THE DIRECT-FIRING
SYSTEM, IN GENERAL, ARE AS FOLLOWS:

1. Steam or gas air heater to supply hot air to the pulverizer for drying the coal as pulverized.
2. Pulverizer fan, known as the primary-air fan, arranged either as an exhauster or as a blower.
3. Pulverizer arranged to operate under suction or pressure.
4. Automatically controlled raw-coal feeder.
5. Coal-and-air conveying lines.
6. Burners.

SOURCE: BABCOCK AND WILCOX, REFERENCE 1.

Furnaces may also be classified with respect to handling of ash as wet bottom and dry bottom.

Wet bottom (slag tap)--molten ash accumulates on lower walls and floor of furnace and flows through slag tap; 50% may be entrained in the flue gases as fly ash. Units may or may not be equipped with slag screens which are water tubes set perpendicular to the gas flow, the purpose of which is to reduce the temperature of the ash particles in suspension below their sticky or tacky temperature to avoid build-up of slag in closely spaced tube banks.

Dry bottom--residual particles are cooled below melting point before contact with heat absorption surfaces--60 to 80% of residuals leave as fly ash.

Other types--these include applications in the metallurgical industry, shown in Figure 6.2.16.

(2) Factors Affecting Emissions

- Principal emission problems include fly ash, particulates, fines, SO_x and NO_x. Tall stacks are employed, usually 400 to 1,000 feet in height. Coal fines may be emitted from the stacks, as well as from vents on coal storage bins and the pulverizer system. Emissions from the combustion system are primarily related to coal-air ratios in the transport system and burners, finess of coal and excess air. Values for these variables must be determined in each situation.

- Typical particulate emissions: a 200 megawatt station burning 1800 tons coal/day will produce 360 tons ash and emit 290 tons particulates/day, uncontrolled; 30 tons/day, controlled. Dust collectors (e.g., baghouses) should be required on stacks and pulverizer system vents.

(3) Fuels, Fuel-Preparation and Transport

- In conducting inventory and other inspections where inspectors must describe equipment, the inspector should gather information sufficient to complete his understanding of the combustion system and to establish normal and abnormal practices with regard to fuel properties, and fuel preparation and transport. This information should

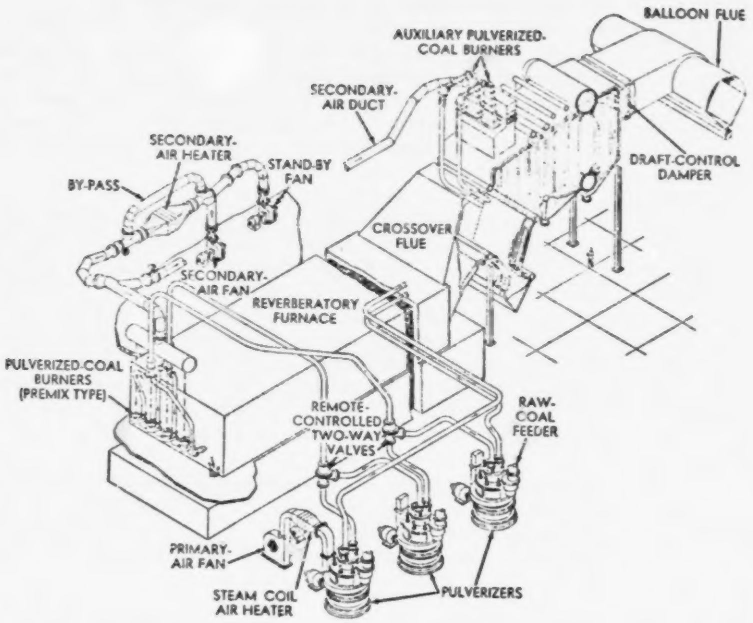

BALLOON FLUE
AUXILIARY PULVERIZED-COAL BURNERS
SECONDARY-AIR DUCT
SECONDARY-AIR HEATER
STAND-BY FAN
BY-PASS
DRAFT-CONTROL DAMPER
CROSSOVER FLUE
SECONDARY-AIR FAN
REVERBERATORY FURNACE
PULVERIZED-COAL BURNERS (PREMIX TYPE)
REMOTE-CONTROLLED TWO-WAY VALVES
RAW-COAL FEEDER
PRIMARY-AIR FAN
STEAM COIL AIR HEATER
PULVERIZERS

Figure 6.2.16. DIRECT-FIRED COPPER REVERBERATORY-FURNACE AND WASTE-HEAT-BOILER ARRANGEMENT

SOURCE: BABCOCK AND WILCOX, REFERENCE 1.

include: grindability, rank, moisture, volatile matter and ash content of coals used in firing. Fuels with moisture content as high as 20% (surface, 15%) can be fired if dried in the pulverizer at 600°F. At least 70% of the pulverized fines should pass through a 200 mesh. In checking the pulverizer equipment, the inspector should report the apparent condition of grinding elements, extent of rejection of oversize fuel, and extent of the production and handling of superfines. The inspector should also determine the grindability of coal which is based on a hardness index. Coals <100 are harder than coals >100.

- The inspector should check the transport system and type of pulverizer used: impact, tube-mill, roll and race, ball and race. He should inquire as to the capacity of the air transport system, and moisture and fineness in bin systems. In general, a high velocity, uniform coal/air mixture is desirable. Air/coal ratios are increased at lower loads and decreased at higher loads. Pitot tube and orifices are frequently used by furnace operators to meter the air in the transport system. This information should be available to the inspector.

- Direct firing-coal feed is adjusted to load demand; primary air supply is regulated to coal feed, or primary air through the pulverizer is controlled proportional to the load demand, and coal feed is automatically adjusted to the rate of the air flow.

- The pulverizer may grind only or may grind, feed, dry, classify, circulate and transport, or these functions may be conducted in separate equipment.

- Dust cleaning devices should be used on bin systems.

(4) Burner

In conducting routine, incident or inventory inspections, the inspector should record the following:

- Burner type: horizontal, vertical, tangential, circular, multiple-intertube multitip, cross-tube (see Figures 6.2.17, 6.2.18, and 6.2.19).

Figures 6.2.17 and 6.2.18 not available for this publication.

Figure 6.2.19 not available for this publication.

- Adjustment of coal/air distributors and nozzles.
- Number bends in coal pipe.
- Use of correcting distributors.
- Dispersion of fuel stream from the piping over the burner area.

(5) Firebox and Firing Conditions:

- Complete combustion with minimum excess air is desirable to maintain fuel stream ignition stability and to reduce particulate emissions.
- Usual excess air is 15 to 40% by weight; excess air of 15 to 22% may help to keep the combustible content of the particulate emission under 10%.
- The inspector should establish burner clearance to confining furnace walls. Fire should show a uniform and symmetrical pattern, predominantly bright with some short dark streaks. Burner flames should not blast against furnace walls. The inspector should check the condition of refractory walls for evidence of flame impingement, and external surface of furnace tubes for corrosion. Tube wastage may be due to high heat release, high sulfur and alkaline coals, and areas deficient in oxygen.

c. Cyclone Furnaces

(1) Function and Types

- Fires crushed coal nearly as fine as pulverized coal into refractory lined cylindrical chamber. The furnace is used for cooling. Combustion air tangentially enters burner and imparts whirling motion to incoming coal, hence cyclone furnace. These furnaces are designed to burn low grades and ranks of high ash, low fusion temperature coal and are used to generate steam, similar to pulverized coal burning equipment. The size range of cyclone units is generally comparable to pulverized fuel units. The allowable range of maximum heat input is 100 to 500 million Btu/hour. The principal types of furnaces are screened and open, as shown in Figure 6.2.21. Coal preparation and feeding systems include bin and storage, Figure 6.2.22.

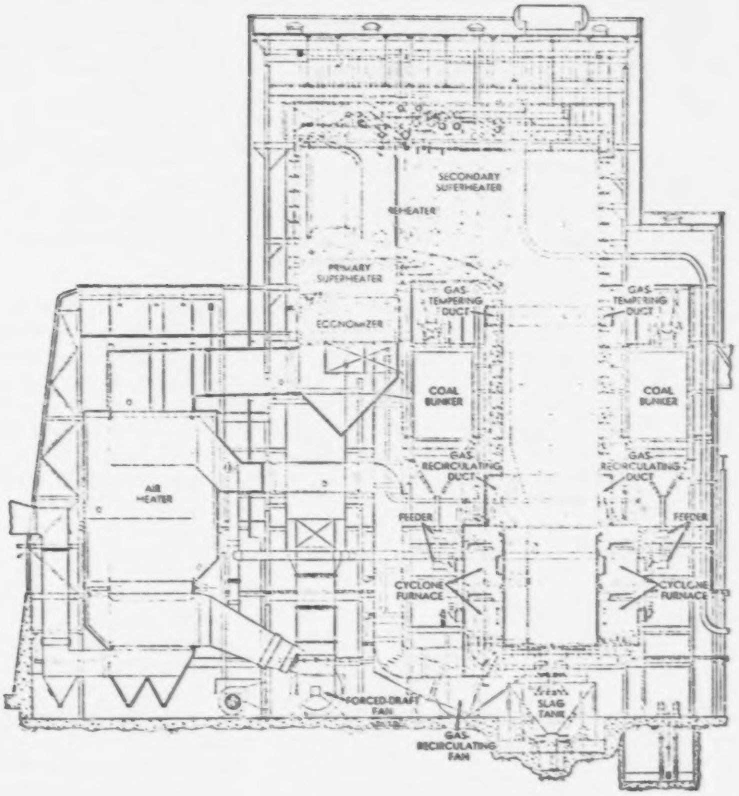
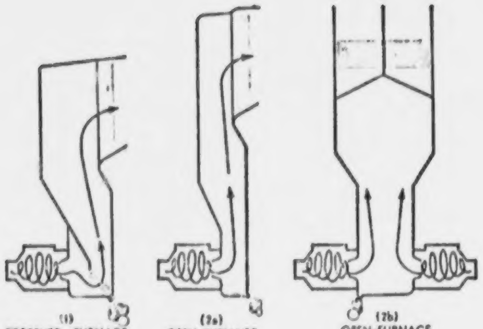

SECONDARY SUPERHEATER
REHEATER
PRIMARY SUPERHEATER
ECONOMIZER
GAS-TEMPERING DUCT
GAS-TEMPERING DUCT
COAL BUNKER
COAL BUNKER
AIR HEATER
GAS-RECIRCULATING DUCT
GAS-RECIRCULATING DUCT
FEEDER
FEEDER
CYCLONE FURNACE
CYCLONE FURNACE
FORCED-DRAFT FAN
SLAG TANK
GAS-RECIRCULATING FAN

Figure 6.2.20. A 700,000-kw-CAPACITY B&W UNIVERSAL-PRESSURE BOILER, ONE OF THE LARGEST IN THE WORLD

SOURCE: BABCOCK AND WILCOX, REFERENCE 1.



(1) SCREENED-FURNACE ARRANGEMENT

(2a) OPEN-FURNACE ARRANGEMENT

(2b) OPEN-FURNACE ARRANGEMENT

Figure 6.2.21. TYPES OF BOILER FURNACES USED WITH CYCLONE FURNACES

SOURCE: BABCOCK AND WILCOX, REFERENCE 1.

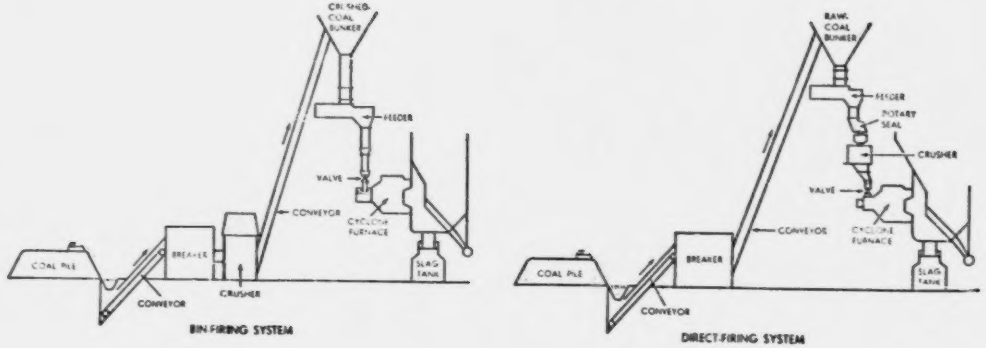

CRUSHED COAL BUNKER
FEEDER
VALVE
CONVEYOR
CYCLONE FURNACE
BREAKER
COAL PILE
SLAG TANK
CONVEYOR
CRUSHER
BIN-FIRING SYSTEM
RAW COAL BUNKER
FEEDER
ROTARY SEAL
CRUSHER
VALVE
CONVEYOR
CYCLONE FURNACE
BREAKER
COAL PILE
SLAG TANK
CONVEYOR
DIRECT-FIRING SYSTEM

Figure 6.2.22. BIN-FIRING AND DIRECT-FIRING SYSTEMS FOR COAL PREPARATION AND FEEDING TO THE CYCLONE FURNACE (SCHEMATIC)

SOURCE: BABCOCK AND WILCOX, REFERENCE 1.

(2) Emissions

15 percent ash is emitted as extremely fine particles; 85% retained as molten slag. Particulates are difficult to collect and high efficiency collectors are required. NO_x emissions are likely to be greater than for other comparable coal fired equipment. Fly ash rate is lower than for pulverized units. A 200 megawatt station, uncontrolled, may emit 30 tons/day fly ash.

(3) Fuel and Fuel Preparation

- Suitability of solid fuel is based primarily on viscosity of slag formed from molten ash. At 2600°F viscosities exceeding 250 poises cause difficulty in tapping slag.
- Petroleum by-products and waste fuels such as bark can be burned. Petroleum products may range in volatile matter from as low as 5% for petroleum coke to as high as 60% for pitch. Coal chars may also be burned. Oil or gas can also be fired in cyclone furnaces (see Figure 6.2.23). Coal is crushed so that 95% passes through 4 mesh screen.

(4) Burners

- The fuel is burned quickly and completely in a small cyclone chamber; the boiler furnace is used only for cooling of flue gases. The coal is ignited by a permanently installed gas lighting or retractable oil lighting torch. Fuel is fired and heat is released at extremely high rate--500,000 to 900,000 Btu/cu. ft./hr. Gas temperatures exceeding 3,000°F are developed. 20 percent of the combustion air enters the cyclone burner. Excess air required is less than 10 percent; 10 to 15 percent with automatic controls.

2. Oil-Burning Equipment

To burn oil in combustion equipment, fuel oil must be atomized into finely divided liquid droplets. This is accomplished by forcing oil under pressure through a nozzle, use of steam or air under pressure (which can range from 1/2 to 1,000 psig), or by mechanical means, as in the rotary cup type of burner.

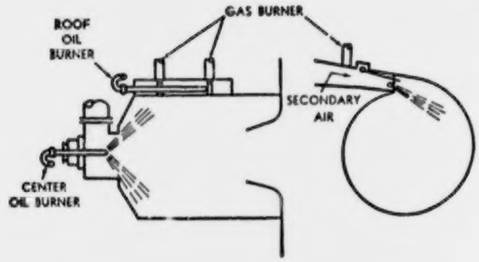

GAS BURNER
ROOF
OIL
BURNER
SECONDARY
AIR
CENTER
OIL BURNER

Figure 6.2.23. OIL AND GAS BURNERS FOR THE CYCLONE FURNACE

SOURCE: BABCOCK AND WILCOX, REFERENCE 1.

Atomizing burners are used primarily in heating, stationary power, locomotive and marine installations. Mechanical atomizing burners of the spray nozzle type are usually used with power plant steam generating units. The rotary cup burner is usually used in low pressure installations.

In the low pressure, air atomizing burner (Figure 6.2.24) most of the combustion air is supplied near the oil orifice at 1/2 to 5 psig. Secondary combustion air flows around the periphery of the mixture. Since most of the combustion air supplied to the burner is close to the burner tip, this type of burner produces a short flame.

In high pressure steam or air atomizing burners, steam or air at pressures ranging from 30 to 150 psig is applied to atomize the oil steam at the burner tip (see Figure 6.2.25). These burners are often used on an oil standby basis. Steam atomizing burners appear to perform well at oil viscosities of 150 to 200 saybolt seconds universal (SSU). Air atomizing burners can operate at 80 to 100 SSU.

Oil pressure atomizing burners. Oil is mechanically atomized by the force of high fuel pressure (75 to 150 psig) through small fixed orifices. The burner performs satisfactorially only over a fairly narrow pressure range.

In the wide range mechanical atomizing burner a strong whirling action is imparted to the oil which is then released through the orifice, while excess oil is drawn off through the central oil line. Proper atomization is dependent upon centrifugal velocities, which require high pressures, e.g., 100 to 200 psig.

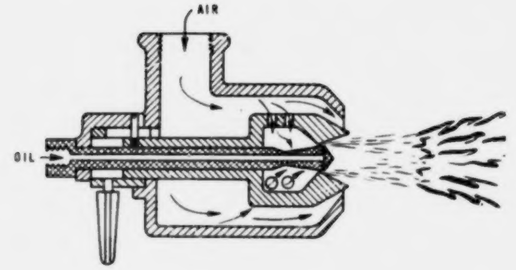


Figure 6.2.24. LOW-PRESSURE, AIR-ATOMIZING OIL BURNER (HAUCK MANUFACTURING CO., 1953)

SOURCE: WALSH, REFERENCE 3.

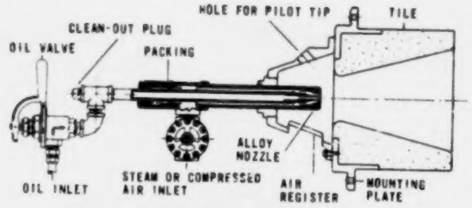

HOLE FOR PILOT TIP
TILE
CLEAN-OUT PLUG
OIL VALVE
PACKING
ALLOY NOZZLE
OIL INLET
STEAM OR COMPRESSED AIR INLET
AIR REGISTER
MOUNTING PLATE

Figure 6.2.25. HIGH PRESSURE, STEAM- OR AIR-ATOMIZING OIL BURNER (NORTH AMERICAN MANUFACTURING CO, 1952)

SOURCE: WALSH, REFERENCE 3.

In the rotary cup burner (Figure 6.2.26) the oil is fed through a hollow rotating shaft. A hollow cup on the end of the shaft throws the oil from its edges in the form of fine liquid droplets. Air is not mixed with the oil before atomization, and combustion air is admitted through an annular port around the rotary cup. Rotary cup burners can be used to burn oils of widely varying viscosity, ranging from distillate to residuals greater than 300 SSU.

Strainers and filters which remove sludge are essential to good combustion. The removal of sludge reduces burner wear and increases burner efficiency. Also, viscosity must be controlled. Fuel oils with viscosities less than 100 SSU can be burned efficiently in almost any burner. Most burners optimally perform at 150 SSU or lower. Distillate oils and some blends are rated at less than 100 SSU.

When oil viscosity is not satisfactory, preheaters must be used, particularly with grades 5 and 6 oil. Oil preheaters are used to improve viscosity, and may be mounted directly on the burner, at the supply tank or any place in between. Preheaters operate with either electricity or steam. Typical oil preheat temperatures necessary to obtain a suitable viscosity for atomization is usually between 150 and 200°F.

The principal air contaminants affected by burner design and operation are oxidizable materials: carbon, carbon monoxide, aldehydes, organic acids, unburned hydrocarbons, and soot and other particulates. The principal causes of smoke and incomplete combustion are:

- Burner and fuel not compatible.
- Burner not properly adjusted or operated.
- Burner improperly maintained.

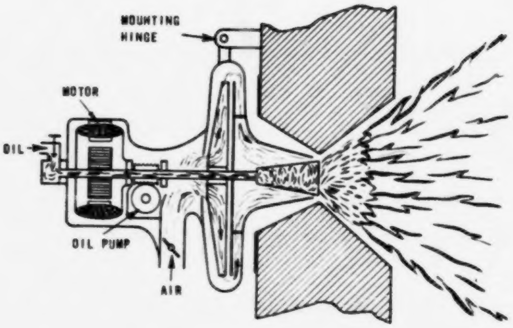

MOUNTING
HINGE
MOTOR
OIL
OIL PUMP
AIR

Figure 6.2.26. ROTARY CUP OIL BURNER (HAUCK MANUFACTURING COMPANY, 1953)

SOURCE: WALSH, REFERENCE 3.

Burner adjustment can be critical. A well adjusted air atomizing unit is capable of producing as little as 12 to 14 lbs./1,000 gallons of heavy oil burned. This would equal .034 to .04 gr./SCFD at 50% excess air during normal operation. Oil burner servicemen should adjust burners, particularly light oil burning installations, to achieve a specified Bachrach limitation, for example #1, with allowance for degradation of performance with operating time. Some burners may need more efficient replacement burners. Some agencies include Bachrach limitations in their legislation. Proper adjustment of burners can result in a 30% decrease in particulate (soot) emissions.

Smaller furnaces using residual oil may have a greater tendency to burn fuel inefficiently, thus causing substantial soot emissions and resulting in relatively higher operating costs.

Table 6.2.16(5) classifies oil-burners according to application and possible pollutants emitted. Common causes of poor combustion in boilers are shown in Table 6.2.17.(17) When lighting off a cold boiler, the operator should

1. Open stack damper and air registers (allow sufficient time for any accumulated gases to be dissipated).
2. Recirculate fuel oil until proper temperature is reached at the burners.
3. Insure sufficient oil pressure on the burner header line.
4. Thoroughly blow out all condensate in the atomizing steam line (make sure atomizing steam to burner is dry).
5. Be sure that burner to be used in "lighting off" is clean.
6. Use small orifice tips (pressure burner).
7. Only one burner (on boilers fitted with multiple burners) should be used until refractory is relatively hot.

Table 6.2.16. CLASSIFICATION OF OIL BURNERS ACCORDING TO APPLICATION AND LIST OF POSSIBLE POLLUTANTS

Burner type	Applications	Oil type usually used	Defects which may cause odors and smoke
Domestic[a]			
Pressure atomizing	Residential furnaces, water heaters	No. 1 or 2	Increased viscosity of oil; nozzle wear; clogged flue, gas passes, or chimney; dirt clogging air inlet; oil rate in excess of design
Rotary	Residential furnaces, water heaters	No. 1 or 2	Increased viscosity of oil; clogged nozzle or air supply; oil rate in excess of design
Vaporizing	Residential furnaces, water heaters	No. 1	Fuel variations; clogged flue gas passages, or chimney; clogged air supply
Commercial, Industrial			
Pressure atomizing	Steam boilers, process furnaces	No. 4, 5	Oil preheat too low or too high; nozzle wear; nozzle partly clogged; impaired air supply; clogged flue gas passages; poor draft; overloading
Horizontal rotary cup	Steam boilers, process furnaces	No. 4, 5, 6	Oil preheat too low or too high; burner partly clogged or dirty; impaired air supply; clogged flue gas passages; poor draft; overloading
Steam atomizing	Steam boilers, process furnaces	No. 5, 6	Oil preheat too low or too high; burner partly clogged or dirty; impaired air supply; clogged flue gas passages; poor draft; overloading; insufficient atomizing pressure
Air atomizing	Steam boilers, process furnaces	No. 5	Oil preheat too low or too high; burner partly clogged or dirty; impaired air supply; clogged flue gas passages; poor draft; overloading; insufficient atomizing pressure

[a] Commercial standard CS-75 established by U.S. Dept. of Commerce requires that all oil burners labeled as complying with the standard shall have smoke-free combustion.

Source: Engdahl, Reference 5.

Table 6.2.17. COMMON CAUSES AND RESULTS OF POOR COMBUSTION

Cause	Result		
	Smoking fire	Carbon formation in the boiler	Pulsating fire
Insufficient air or too much oil (improper air-fuel ratio)	X	X	X
Poor draft	X	Sometimes	X
Excess air (causing white smoke)	X		
Dirty or carbonized burner tip (caused by improper location, insufficient cleaning at regular intervals)	X	X	
Carbonized or damaged atomizing cup (rotary cup)	X	X	
Worn or damaged orifice hole	X	X	
Improper burner adjustment (diffuser plate protruding improper distance)	X	X	Sometimes
Oil pressure to burner too high or too low	X	X	
Oil viscosity too high	X	Sometimes	
Oil viscosity too low (too high fuel oil temperature)		X	X
Forcing burner (especially after initial light-off or when combustion space is relatively cold)	X	X	X
Insufficient atomizing steam	X	X	
Water in fuel oil		X	X
Dirty fuel oil	X	X	X
Fluctuating oil pressure	Intermittent		X
Incorrect furnace construction causing flame and oil impingement		X	
Carbon clinker on furnace floor or walls	X	X	
Incorrect atomizer tip size		X	
Condensate in atomizing steam	X		X
Atomizing steam pressure too high			X
Furnace cone angle too wide			X
Furnace cone angle too narrow (making it necessary to have atomizer in maximum position)		X	X
Atomizer not immediately removed from burner being secured		X	

Source: Parmelee and Elliot, Reference 17.

8. Use most centrally located burner during the initial period.

9. Allow sufficient time to bring cold boiler up very gradually to operating temperature and pressure. (2 to 3 hours for water tube boilers and 8 to 10 hours for fire-tube boilers. This time may be less for smaller boilers.)

3. Gas-Burning Equipment

Gas fired burners are of three types: atmospheric, multiple port, and forced draft, as shown in Figures 6.2.27 and 6.2.28.(3) In gas fired equipment, the jet of raw gas draws with it atmospheric or primary air which mixes with the gas in the burner. Secondary air is drawn into the combustion chamber by action of draft or thermal head. Industrial gas burners are usually of the atmospheric or power driven type in which intense mixing is provided by a blower.

Emissions from gas burning equipment are generally lower than for other operations. Smoke from this equipment is rare, although units have been known to smoke when dampers or secondary air regulators are severely out of adjustment. The generally smokeless condition of this equipment can cause complacency especially with regard to CO and NO_x emissions, which can be considerable. Multiple port burners are, in general, associated with comparatively larger NO_x emissions. Combustion efficiency may be generally lower than for coal and oil fired operations for similar reasons. Air/fuel ratios can vary widely and should be periodically checked. Excess air in gas fired equipment should be maintained below 25%.

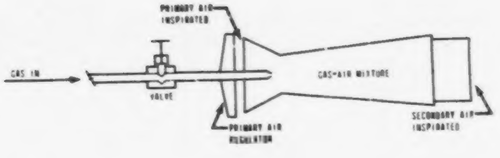

PRIMARY AIR
INSPIRATED
GAS IN
VALVE
GAS-AIR MIXTURE
PRIMARY AIR
REGULATOR
SECONDARY AIR
INSPIRATED

Figure 6.2.27. TYPICAL ATMOSPHERIC GAS BURNER

SOURCE: WALSH, REFERENCE

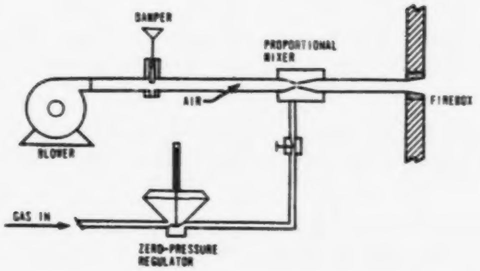

DAMPER
PROPORTIONAL
MIXER
AIR
FIREBOX
BLOWER
GAS IN
ZERO-PRESSURE
REGULATOR

Figure 6.2.28. A MULTIPLE-PORT BURNER (NONPRIMARY AERATED) INSTALLED IN A VAPOR INCINERATOR

SOURCE: WALSH, REFERENCE

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III. INCINERATORS

A. INTRODUCTION

Incineration is the disposal of waste materials by burning in an enclosed structure especially designed for this purpose. The boxlike or cylindrical structure serves to confine the fuel pile, regulate the air supply and provide some control over the rate and degree of combustion.

Incinerators are a major source of smoke, particulates and a wide variety of gaseous contaminants, particularly in communities that rely on them as a principal means of waste disposal. Proper combustion in incinerators is a science and skill beyond the capability and patience of most operators. Provided that acceptable methods of waste disposal are available--such as sanitary land fills--the use of small incinerators by the residential and much of the commercial and industrial sectors of the economy should be prohibited, as has been done in several communities. Many urban areas are establishing new regulations limiting emissions from incinerators to 0.1 grains per standard cubic foot or .20 lbs per 100 lbs charged and more stringent opacity requirements. Specific requirements for incinerator design, auxiliary combustion equipment and particulate control systems are also being established. This legislation will thus prevent the installation of incinerators that cannot meet emission standards.

The principles of incinerator combustion are similar to those described in the fuel-burning section of this chapter. In the burning of solid wastes, three stages are involved: (1) water evaporation, (2) distillation and combustion of volatile matter and (3) reaction of fixed carbon with oxygen. Effective incinerator design depends on the satisfaction of requirements for time, temperature, turbulence and oxygen. This is best achieved by the multiple-chamber type of incinerator design. Single-chamber incinerators, as a class, cannot meet new emission standards and their use should not be permitted.

The variability of the composition, moisture, volatility and weight of waste materials and charging rates and methods presents problems which differ from those of fuel-burning in which fuels, burners and other factors are maintained on a comparatively steady-state basis and are subject to a greater degree of control on the part of operators. Particular attention must be paid, with incinerators, to assure the following:

- Air and fuel must be in proper proportion. Adequate provision should be given for underfire and overfire air (where required). Admission of air due to infiltration through cracks and doors should be prevented.
- Air and fuel, especially combustible gases, must be mixed adequately.
- Temperature must be sufficient for ignition of both the solid refuse and the gaseous components. Low temperatures will cause incomplete oxidation reactions and consequent air pollution emissions; excessive high temperatures will cause equipment and structural damage, refractory failure, slag build-up in the furnace linings (in large installations) and increases in oxides of nitrogen emissions.
- Furnace volumes must be large enough to provide the retention time needed for complete combustion.
- The incinerator should have provisions to dry the refuse in order to facilitate ignition. This can be accomplished through design, operation, moving grates or the use of auxiliary burners.
- Furnace proportions must be such that ignition temperatures are maintained and fly ash entrainment is minimized.

Enforcement personnel will be primarily concerned with the identification of incinerators by design and type, identification of incinerator appurtenances, construction materials and the condition and operation of incinerators. The inspector should be familiar with the operating instructions for specific incinerators and equipment, such as auxiliary fuel burners, afterburners, methods of priming and light-off of cold incinerators and burning of highly combustible materials, air port adjustments and refuse charging and burndown procedures.

B. INCINERATOR DEFINITIONS AND TERMINOLOGY

The definitions given below apply to incinerators as typically defined in ordinances and give commonly used nomenclature.

INCINERATOR TYPES(1)

1. INCINERATOR: Any device, apparatus, equipment or structure used for destroying, reducing or salvaging by fire any material or substance including but not limited to refuse, rubbish, garbage, trade waste, debris or scrap or a facility for cremating human or animal remains.

2. COMMON INCINERATOR: An incinerator designed and used to burn waste materials of Types 0, 1, 2, and 3 only, in all capacities not exceeding 2,000 pounds per hour of waste material input. (See Table 6.3.1.)

3. SINGLE-CHAMBER INCINERATOR: Incinerator in which one chamber serves for ignition, combustion and ash removal.

4. SPECIAL INCINERATOR: Municipal, pathological waste, or trade waste incinerator of any burning capacity, or any incinerator with a burning capacity in excess of 2,000 pounds per hour.

5. MUNICIPAL INCINERATOR: An incinerator owned or operated by government or by a person who provides incinerator service to government or others, and designed and used to burn waste materials of any and all types, 0 to 6 inclusive.

6. PATHOLOGICAL WASTE INCINERATOR: An incinerator designed and used to burn Type 4 waste materials, primarily human and animal remains, in all burning capacities. Crematoriums are included in this category.

7. TRADE WASTE INCINERATOR: An incinerator designed and used to burn waste material primarily of Types 5 and 6, either separately or together with waste materials of Types 0, 1, and 3.

8. FLUE-FED APARTMENT INCINERATORS: Either a single-chamber or multiple-chamber type of incinerator in which the chimney also serves as a chute for refuse charging. Some incinerators may have exhaust flues separate from the charging chutes.

Table 6.3.1 CLASSIFICATION OF WASTE TO BE INCINERATED

Classification of Wastes Type	Description	Principal Components	Approximate Composition % by Weight	Moisture Content %	Incombustible Solids %	B. T. U. Value/lb. of Refuse as fired	B. T. U. of Aux. Fuel Per lb. of Waste to be included in Combustion Calculations	Recommended Min. B. T. U./hr. Burner Input per lb. Waste
*0	Trash	Highly combustible waste, paper, wood, cardboard cartons, including up to 10% treated papers, plastic or rubber scraps; commercial and industrial sources	Trash 100%	10%	5%	8500	0	0
*1	Rubbish	Combustible waste, paper, cartons, rags, wood scraps, combustible floor sweepings; domestic commercial, and industrial sources	Rubbish 80% Garbage 20%	25%	10%	6500	0	0
*2	Refuse	Rubbish and garbage; residential sources	Rubbish 50% Garbage 50%	50%	7%	4300	0	1500
*3	Garbage	Animal and vegetable wastes, restaurants, hotels, markets; institutional, commercial, and club sources	Garbage 65% Rubbish 35%	70%	5%	2500	1500	3000
4	Animal solids and organic wastes	Carcasses, organs, solid organic wastes; hospital, laboratory, abattoirs, animal pounds, and similar sources	100% Animal and Human Tissue	85%	5%	1000	3000	8000 (5000 Primary) (3000 Secondary)
5	Gaseous, liquid or semi-liquid wastes	Industrial process wastes	Variable	Dependent on predominant components	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey
6	Semi-solid and solid wastes	Combustibles requiring hearth, retort, or grate burning equipment	Variable	Dependent on predominant components	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey

*The above figures on moisture content, ash, and B. T. U. as fired have been determined by analysis of many samples. They are recommended for use in computing heat release, burning rate, velocity, and other details of incinerator designs. Any design based on these calculations can accommodate minor variations.

SOURCE: Kaiser, Reference 2.

9. WOOD-WASTE BURNING INCINERATORS: These include wigwam, silo type or multiple-chamber incinerators designed to burn wood waste produced from lumber mills and wood working industries. These incinerators are usually continuously fed from pneumatic and mechanical feed systems.

10. MULTIPLE CHAMBER INCINERATOR: An incinerator with two or more refractory-lined combustion chambers in series physically separated by refractory walls, interconnected by gas passages, and employing adequate design parameters necessary for maximum combustion of the waste materials.

    Multiple-chamber incinerators are of two types: Retort, in which the flow of gases is returned through a "U" arrangement and, the In-line type, in which the flow of gases is through each of three successive chambers. The former is intended for smaller operations, the latter for larger operations.

    Multiple-chamber incinerator design principles and standards can be applied to all incinerator functions listed here, including apartment flue-fed incinerators.

11. MOBILE MULTIPLE CHAMBER: Specially designed and constructed multiple-chamber incinerators mounted on wheels, constructed of light-weight materials and limited in size to comply with state vehicle codes. These incinerators are intended for use in land-clearing operations as a substitute for open burning.

12. RECLAMATION INCINERATORS: A special incinerator designed to reclaim electrical equipment windings or to debond brake shoes.

INCINERATOR NOMENCLATURE(3)

1. AUXILIARY-FUEL FIRING EQUIPMENT: Equipment to supply additional heat, by the combustion of an auxiliary fuel, for the purpose of attaining temperatures sufficiently high (a) to dry and ignite the waste material, (b) to maintain ignition thereof, and (c) to effect complete combustion of combustible solids, vapors, and gases.

2. BAFFLE: A refractory construction intended to change the direction of flow of the products of combustion.

3. BREECHING: The connection between the incinerator and the stack.

4. BREECHING BY-PASS: An arrangement of breeching and dampers to permit the intermittent use of two or more passages for products of combustion to the stack or chimney.

5. BRIDGE-WALL: A partition wall between chambers over which pass the products of combustion.

6. BTU (BRITISH THERMAL UNIT): The quantity of heat required to increase the temperature of one pound of water from 60° to 61°F.

7. BURNERS: Primary--A burner installed in the primary combustion chamber to dry out and ignite the material to be burned.

   Secondary--A burner installed in the secondary combustion chamber to maintain a minimum temperature of about 1400°F. It may also be considered as an after-burner.

   After-burner--A burner located so that the combustion gases are made to pass through its flame in order to remove smoke and odors. It may be attached to, or be separated from the incinerator proper.

8. BURNING AREA: The horizontal projected area of grate, hearth, or combination thereof on which burning takes place.

9. BURNING RATE: The amount of waste consumed, usually expressed as pounds per hour per square foot of burning area. Occasionally expressed as BTU per hour per square foot of burning area, which refers to the heat liberated by combustion of the waste.

10. CAPACITY: The amount of a specified type or types of waste consumed in pounds per hour. Also may be expressed as heat liberated, BTU per hour, based upon the heat of combustion of the waste.

11. CHECKER-WORK: Multiple openings above the bridge-wall, and/or below the drop arch, to promote turbulent mixing of the products of combustion.

12. CHUTE, CHARGING: A pipe or duct through which wastes are conveyed from above to the primary chamber, or to storage facilities preparatory to burning.

13. COMBUSTION AIR: Primary--Air introduced to the primary chamber through the fuel bed by natural, induced, or forced draft.

    Secondary--Air supplied in the secondary combustion chamber usually through the bridge wall (see Figure 6.3.1 in part C).

    Theoretical--Air, calculated from the chemical composition of waste, required to burn the waste completely without excess air. Also designated as Stoichiometric air.

    Excess--Air supplied in excess of theoretical air, usually expressed as a percentage of the theoretical air.

14. COMBUSTION CHAMBER: Primary--Chamber where ignition and burning of the waste occur.

Secondary--Chamber where combustible solids, vapors, and gases from the primary chamber are burned and settling of fly ash takes place.

15. CURTAIN WALL OR DROP ARCH: A refractory construction or baffle which serves to deflect gases in a downward direction.

16. DAMPER: A manual or automatic device used to regulate the rate of flow of gases through the incinerator.

Barometric--A pivoted, balanced plate, normally installed in the breeching, and actuated by the draft.

Guillotine--An adjustable plate normally installed vertically in the breeching, counterbalanced for easier operation, and operated manually or automatically.

Butterfly--An adjustable, pivoted, plate normally installed in the breeching.

Sliding--An adjustable plate normally installed horizontally or vertically in the breeching.

17. DRAFT: The pressure difference between the incinerator, or any component part, and the atmosphere, which causes the products of combustion to flow from the incinerator to the atmosphere.

Natural--The negative pressure created by the difference in density between the hot flue gases and the atmosphere.

Induced--The negative pressure created by the action of a fan, blower, or ejector, which is located between the incinerator and the stack.

Forced--The positive pressure created by the action of a fan or blower, which supplies the primary or secondary air.

18. FLUE GAS WASHER OR SCRUBBER: Equipment for removing fly ash and other objectionable materials from the products of combustion by means of sprays, wet baffles, etc. Also reduces excessive temperatures of effluent.

19. FLY ASH: All solids including ash, charred paper, cinders, dust, soot, or other partially incinerated solid matter, carried in the products of combustion.

20. FLY ASH COLLECTOR: Equipment for removing fly ash from the products of combustion.

21. GRATE: A surface with suitable openings, to support the fuel bed and permit passage of air through the fuel. It is located in the primary combustion chamber and is designed to permit the removal of the unburned residue. It may be horizontal or inclined, stationary or movable, and operated manually or automatically.

22. HEARTH: Cold drying--A surface upon which wet waste material is placed to dry prior to burning by the actual hot combustion gases passing only over the wet material.

    Hot drying--A surface upon which wet material is placed to dry by the action of hot combustion gases that pass successively over the wet material and under the hearth.

23. HEAT OF COMBUSTION: The amount of heat, usually expressed as BTU per pound of as-fired or dry waste, liberated by combustion at a reference temperature of 68°F. With reference to auxiliary gas it is expressed as BTU per standard cubic foot, and to auxiliary oil as BTU per pound or gallon.

24. HEAT RELEASE RATE: The amount of heat liberated in the primary combustion chamber, usually expressed as BTU per hour per cubic foot.

25. HEATING VALUE: Same as heat of combustion.

26. INCINERATOR: Equipment in which solid, semi-solid, liquid or gaseous combustible wastes are ignited and burned, the solid residues of which contain little or no combustible material.

27. MIXING CHAMBER: A chamber usually placed between the primary combustion chamber and an expansion chamber wherein thorough mixing of the products of combustion is accomplished by turbulence created by increased velocities of gases, checkerwork, and/or changes in direction of the gas flow.

28. SETTLING CHAMBER: Chamber designed to reduce the velocity of the gases in order to permit the settling out of fly ash. It may be either part of, adjacent to, or external to the incinerator.

29. SPARK ARRESTER: A screen-like device located on top of the stack or chimney, to prevent incandescent material above a given size from being expelled to the atmosphere.

30. STACK OR CHIMNEY: A vertical passage whether of refractory, brick, tile, concrete, metal or other material or a combination of any of these materials for conducting products of combustion to the atmosphere.

C. MULTIPLE-CHAMBER INCINERATORS

1. General Principles

Multiple-chamber incinerators are constructed of two or more combustion chambers and are specifically designed to improve combustion and to minimize the emissions of air pollutants. The design features provide time, temperature and turbulence sufficient to maximize the speed and completeness of the combustion reaction.

Multiple-chamber incinerators have found widespread use in Air Quality Control Regions where stringent emission regulations are in effect or where the use of single-chamber incinerators is prohibited. These incinerators are used for a wide variety of purposes, including general refuse disposal, flue-fed apartment house incinerators, waste wood incineration, pathological waste, wire reclamation and municipal incinerators. Comparison of emissions between single chamber and multiple-chamber general refuse incinerators is shown in Table 6.3.2.(3)

Multiple-chamber incinerators provide a two-stage combustion process. Primary combustion includes drying, volatilization and ignition of the solid wastes. Secondary combustion includes oxidation of gases and particulate matter released by primary combustion with consequent combustion of unburned gases, elimination of odors and combustion of the carbon suspended in the gases. The chambers are interconnected by fire and curtain wall ports which by their position and design effect turbulent mixing of the gaseous flow, in a mixing chamber, and expansion and final oxidation in the secondary combustion chamber, as shown in Figures 6.3.1 and 6.3.2.(5) Fly ash and particulate matter are collected in the combustion chamber by wall impingement, and settling due to centrifugal and gravitational action. The gases finally discharge through a stack or a combination of gas cooler, such as a water spray chamber and induced draft system.

Multiple-chamber incinerators comprise two basic types: retort and in-line as shown in Figures 6.3.1 and 6.3.2. The retort type offers advantages of compactness and structural economy due to its cubic shape and reduction in exterior well length and is applicable to burning rates ranging from 50 to 750 pounds per hour.(5) The basic features of this type of incinerator are as follows:

Table 6.3.2. COMPARISON BETWEEN AMOUNTS OF EMISSIONS FROM SINGLE AND MULTIPLE-CHAMBER GENERAL REFUSE INCINERATORS

Item	Multiple Chamber	Single Chamber
Particulate matter, gr/scf at 12% CO_2	0.11	0.9
Volatile matter, gr/scf at 12% CO_2	0.07	0.5
Total, gr/scf at 12% CO_2	0.19	1.4
Total, lb/ton refuse burned	3.50	23.8
Carbon monoxide, lb/ton of refuse burned	2.90	197 to 991
Ammonia, lb/ton of refuse burned	0	0.9 to 4
Organic acid (acetic), lb/ton of refuse burned	0.22	<3
Aldehydes (formaldehyde), lb/ton of refuse burned	0.22	5 to 64
Nitrogen oxides, lb/ton of refuse burned	2.50	<0.1
Hydrocarbons (hexane), lb/ton of refuse burned	<1	---

SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 4.

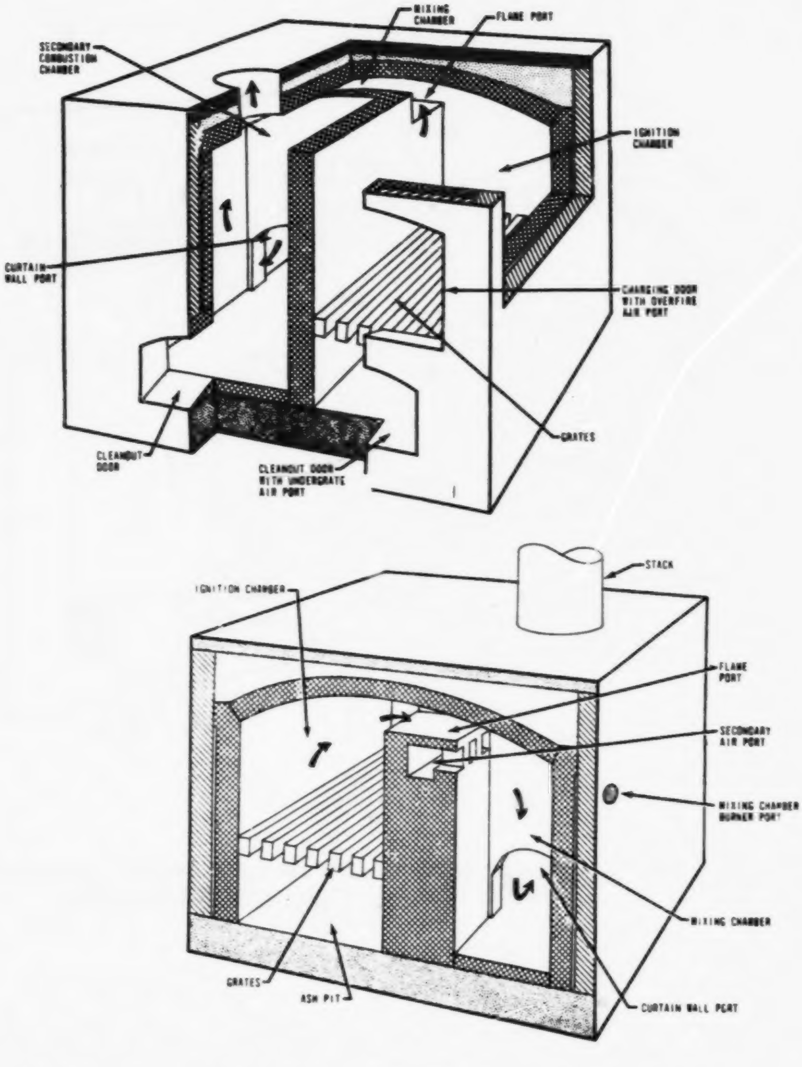

SECONDARY COMBUSTION CHAMBER
MIXING CHAMBER
FLAME PORT
IGNITION CHAMBER
CURTAIN WALL PORT
CHARGING DOOR WITH OVERFIRE AIR PORT
GRATES
CLEANOUT DOOR
CLEANOUT DOOR WITH UNDERGRATE AIR PORT
STACK
IGNITION CHAMBER
FLAME PORT
SECONDARY AIR PORT
MIXING CHAMBER BURNER PORT
MIXING CHAMBER
GRATES
ASH PIT
CURTAIN WALL PORT

Figure 6.3.1. CUTAWAY OF A RETORT MULTIPLE-CHAMBER INCINERATOR (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 4)

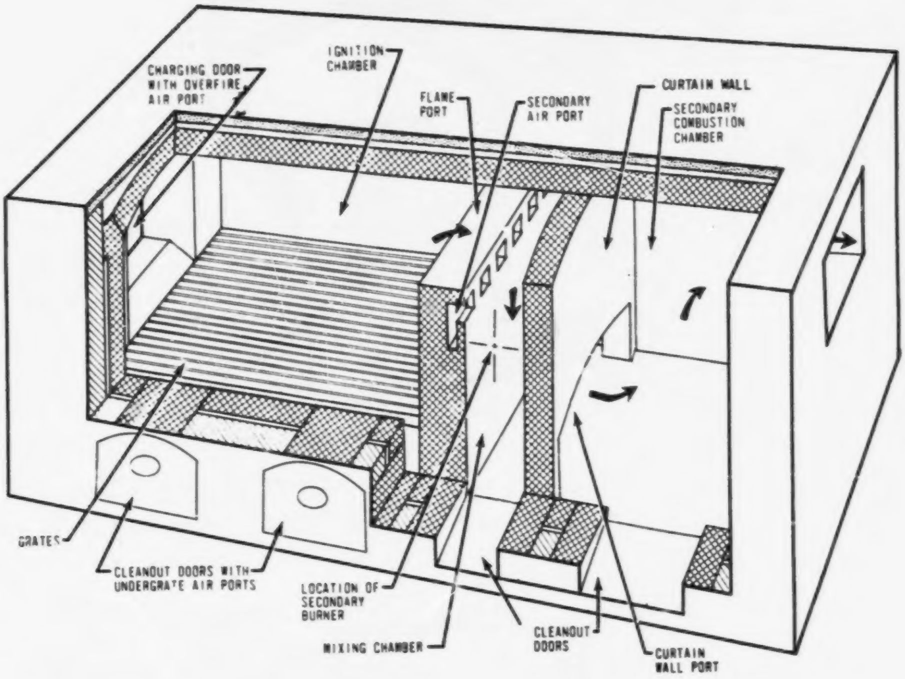

IGNITION CHAMBER
CHARGING DOOR WITH OVERFIRE AIR PORT
FLAME PORT
SECONDARY AIR PORT
CURTAIN WALL
SECONDARY COMBUSTION CHAMBER
GRATES
CLEANOUT DOORS WITH UNDERGRATE AIR PORTS
LOCATION OF SECONDARY BURNER
MIXING CHAMBER
CLEANOUT DOORS
CURTAIN WALL PORT

Figure 6.3.2. CUTAWAY OF AN IN-LINE MULTIPLE-CHAMBER INCINERATOR (SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 4)

- The arrangement of the chambers causes the combustion gases to flow through 90-degree turns in both lateral and vertical directions.
- The return flow of the gases permits the use of a common wall between the primary and both secondary combustion chambers.
- Bridge wall thickness under the flame port is a function of dimensional requirements in the mixing and combustion chambers. The resulting bridge wall construction is unwieldy in incinerators in the size range above 500 pounds per hour.

In-line types of incinerators are generally applicable for burning rates in excess of 750 to more than 1000 pounds per hour. Basic features include:

- Flow of the combustion gases straight through the incinerator with 90-degree turns only in the vertical direction.
- The in-line arrangement of the component chambers giving a rectangular plan to the incinerator. This style is readily adaptable to installations that require separated spacing of the chambers for operating, maintenance or other reasons.
- All ports and chambers extending across the full width of the incinerator.

2. General Inspection Points--Multiple Chamber Incinerators

Emission control is built into the design of multiple-chamber incinerators, provided that the incinerator is used for the purpose for which it is designed and is properly operated and maintained. Even properly designed incinerators can emit excessive emissions through neglect or through exceeding design parameters. Permit or licensing systems should assure that the correct application is made for any given design; enforcement operations should assure that the incinerator is properly operated and maintained.

The design and construction of multiple-chamber incinerators vary considerably with the types of waste to be burned, charging rates and methods and space requirements. The inspector should be able to recognize types of incinerator designs and differences in construction in relation to a given use. The common types of applications that will be of interest to the inspector include the following:

(1) General refuse incinerators.

(2) Flue-fed incinerators (apartment houses)

(3) Wood-burning incinerators.

(4) Pathological waste incinerators.

(5) Reclamation and debonding incinerators.

Operating practices with respect to some of these incinerators are described in other parts of this section, below. This section is concerned with inspection points that generally apply to all incinerator types.

a. Composition of Refuse

An important inspection point is the volume and composition of the refuse being charged to the incinerator. The type of refuse available increasingly presents problems in incinerator design and operation. Both the volume of solid waste being generated and the average Btu content of municipal refuse are rapidly increasing. Refuse currently contains substances such as plastics, which burn with great difficulty or tend to emit large volumes of dense smoke, organics, particulates and other contaminants. Table 6.3.1 gives a commonly used classification of incinerator wastes and Table 6.3.3 can be used as a guide for estimating incinerator capacities, quantities of refuse charged, burning rates and the heat value of refuse.(6)

Table 6.3.3. DETERMINATION OF INCINERATOR CAPACITY

GENERAL DATA:

A. To help determine capacities of Industrial Incinerators, the cubic foot unit measurement may be the simplest. The following information may be used:

1.	15 Gallon Garbage Can 16" dia. x 22" high	2.0 cubic feet
2.	26 Gallon Garbage Can 18" dia. x 24" high	3.6 " "
3.	31 Gallon Garbage Can 21" dia. x 25-1/2" high	4.1 " "
4.	Oil Drum (50 gallon)	6.0 " "
5.	Bushel (U.S. Standard)	1.25 " "
6.	Gallon (U.S. Standard)	.134 " "
7.	One Cubic Yard	27.0 " "
8.	7.5 Gallons	1.0 " "

TRANSLATING CUBIC FEET INTO POUNDS

B.	1.	Dry rubbish, waste paper variety	App. 4 to 7 lbs. per cubic foot
	2.	Wood Waste	App. 8 to 10 lbs. per cubic foot
	3.	Average Mixed Refuse	App. 6 to 8 lbs. per cubic foot

GARBAGE DENSITY

C.	1.	Garbage, 75% moisture content	App. 40 lbs per cubic foot
	2.	The variable in garbage is the moisture content. MORE MOISTURE, MORE WEIGHT	
	3.	Water	62.4 lbs per cubic foot

B.T.U. VALUES

D.	1.	Ordinary waste paper	5-7m BTU per pound
	2.	Wood Waste	8m BTU per pound
	3.	Waxed coated paper waste	8-9m BTU per pound

GRATE BURNING RATE

E.	1.	Ordinary Waste Paper	25 lbs. per hr. per sq. ft. grate area
	2.	Wood Waste	30 lbs. per hr. per sq. ft. grate area
	3.	Waxed and coated paper	40 lbs. per hr. per sq. ft. grate area

SOURCE: McNavlin, Reference 6.

Refuse usually consists of dry combustibles, non-combustibles and moisture. The major source of the dry combustible portion originates in plant life and includes such items as paper, wool, natural textiles, vegetable wastes, brush and leaves. Cellulose, the basic ingredient found in all of these materials, has a calorific value of 7526 Btu per pound.

A second major source of dry combustibles includes hydrocarbons, fats, oils, waxes, resins, synthetics (plastics and textiles), rubber, linoleum and similar materials with calorific values ranging up to 19,000 Btu per pound.

The moisture content varies with any particular source of refuse. Food waste and greens, for example, are high in moisture--about 75% when fresh. Paper products, wood, and natural textiles readily absorb moisture. Metals are not combustibles, but will oxidize in the fire to varying degrees and thus produce heat as well as consume oxygen.(2)

The ash remaining after the combustibles have been burned, together with the dry mineral oxides in the incinerator charge, present in crockery, bricks, glass, and dirt, may be considered to be inert. Trade magazines and junk mail will have a high ash content due to the clay fillers and sizing used in producing smooth printing papers.

b. Refractories

Refractories are materials used to line the interior surfaces of incinerators and other combustion equipment for the purpose of reflecting and maintaining heat. The interior surfaces include combustion chambers, mixing chambers, arches, subsidence chambers, breechings and stacks.

Refractories are classified according to their physical and chemical properties, which may vary considerably. These include heat conductivity, chemical resistivity, thermal expansion characteristics, hardness and strength. Most refractories are composed wholly or in part of alumina, magnesia and silica although chromite and zircon are common synthetic or artificial refractories. Many of these materials are interground with kaolin, the oldest and most widely used natural refractory.(7,8)

Since the combustion efficiency of the incinerator depends on its ability to maintain heat, the type and condition of the refractory should be checked. Spalling is the breaking away of the refractory, usually of the outer surface. Slagging is the destruction that occurs from the buildup of flux on the refractory surface. Softening and erosion of refractories will also occur as a result of temperatures exceeding 2000°F. Refractories may also be damaged from abrasion due to tools, materials, or gases.

Refractory specifications depend upon the specific incinerator application, particularly with respect to refuse type and Btu content. Mineralogically stable, high melting point refractories that are dense, of low porosity and most resistant to slagging and spalling should be used where comparatively high combustion temperatures occur particularly with respect to wood burning incinerators, municipal incinerators and pathological waste burning incinerators. Recommended refractories are shown in Table 6.3.4.

c. Insulation Requirements(8)

Where the incinerator is constructed with a steel plate exterior wall, insulation must be used between the refractory wall and the steel plate. A high-temperature insulating block should be used.

Table 6.3.4. RECOMMENDED TYPES OF MULTIPLE-CHAMBER INCINERATOR REFRACTORIES

1. High Temperature Block Insulation, service temperature up to 1800°F (ASTM C-392-63 Class 2).

2. High-Heat-Duty Firebrick, spall resistant, 10 percent panel spalling loss at 2910°F (ASTM C-106-67).

3. Super-Duty Firebrick, spall resistant, 4 percent maximum spalling loss at 3000°F (ASTM C-106-67).

4. Class C, Hydraulic Castable Refractory, service temperature rated at 2600°F maximum (ASTM C-213-66 Class C).

5. Class D, Hydraulic Castable Refractory, applicable to high heat flux areas of incinerators, such as the arches of pathological incinerators; service temperature at 2800°F maximum (ASTM C-312-66 Class D).

6. Class Q, Insulating Castable, for direct flame radiation (ASTM C-401-60 for Class Q Insulating Castables).

7. Class O, Insulating Castable, where direct flame radiation is not involved, as in a stack (ASTM C-401-60 for Class O Insulating Castables).

8. High-Duty Plastic Refractory, high-duty air setting plastic refractory, 15 percent panel spalling loss at 2910°F; minimum type of recommended air-setting plastic refractory (ASTM C-176-67).

9. Super-Duty Plastic Refractory, recommended for use in areas of high heat flux, such as arches of pathological incinerators, 5 percent panel spalling loss at 3000°F (ASTM C-176-67).

Minimum thickness for insulation is 2 inches. Units larger than 500 pounds per hour should have 2-1/2 inches. Loose-fill insulation is not satisfactory because of its packing into the lower portion of the unit over long periods of time. When the exterior wall is of regular clay brick construction, a minimum of 1 inch air space between the exterior brick and the refractory brick, with adequate venting of the insulating air space should be provided.

d. Charging Doors(8)

Guillotine charging doors used in recommended designs should be lined with refractory material with a minimum service temperature of 2600°F. Units of less than 100 pounds per hour capacity should have door linings at least 2 inches thick. In the size range of 100 to 350 pounds per hour, lining thickness should be increased to 3 inches. From 350 pounds per hour to 1000 pounds per hour, the doors should be lined with 4 inches of refractory. On units of 1000 pounds per hour and larger, linings should be 6 inches thick.

e. Air Inlets(8)

All combustion air inlets should provide positive control. While round "spinner" controls with rotating shutters should be used for both underfire and overfire air openings in retort incinerators, they should only be used for underfire air openings in the in-line incinerator. Rectangular ports with butterfly or hinged dampers should be provided for all secondary air openings and overfire air openings of in-line incinerators. All air inlet structures should be of cast iron. Sliding rectangular dampers become inoperative and should not be used.

f. Clearance(8)

Incinerators should be installed to provide a clearance to combustible material of not less than 36 inches at the sides and rear, and not less than 48 inches above, and not less than 8 feet at the front of the incinerator; except in the case where an incinerator is encased in brick, then the clearance may be 36 inches at the front and 18 inches at the sides and rear. A clearance of not less than 1 inch should be provided between incinerators and walls or ceilings of noncombustible construction. Walls of the incinerator should never be used as part of the structural walls of the building.

g. Stack Viewer(8)

When possible, it is advisable to arrange a system of mirrors to allow an incinerator operator, who would otherwise be unable to see the top of the stack because of his location, to view the stack outlet.

h. Sampling Ports(8)

Each new incinerator stack should have two sampling ports 3-1/2 inches in diameter. Each port should be positioned in the stack at right angles to each other. They should be located, when possible, eight to ten stack diameters downstream from any bend or disturbance of gas flow, and two stack diameters upstream of the exit of the stack. The ports should be provided with suitable removable, replacement caps.

i. Auxiliary Gas Burners(8)

(1) Incinerators Requiring Burners

Secondary burners alone need be installed on incinerators that are to be used solely to burn Type 0 waste. If the incinerator is to burn wastes of Types 1, 2, 3 or 4, both primary and secondary burners should be installed. The need for burners in incinerating other types of waste is dictated by the nature of the waste itself.

(2) Types of Natural Gas Burners Recommended[8]

Incinerators having a capacity of less than 200 pounds per hour that use burners rated at less than 400,000 Btu per hour may be of either the atmospheric or power-burner type. In either case, a continuously or intermittently burning stable pilot adequate to ensure safe, reliable ignition should be installed. A flame safeguard should be used so that no gas can flow to the main burner unless satisfactory ignition is assured. The response time of this flame safeguard to de-energize the gas shutoff device on flame failure should not exceed 180 seconds.

Auxiliary burners on incinerators with ratings of 200 pounds per hour or more, i.e., those equipped with a fan and scrubber, should be of the power-burner type, because this type of burner usually retains its flame better when a fan is used to induce draft. For burners with ratings of more than 400,000 Btu per hour input, the burner equipment shall be of the power type that utilizes a forced-draft blower to supply air needed for combustion under controlled conditions. A continuously or intermittently burning pilot should be used to ensure safe and reliable ignition. Automatic spark ignition should be used on pilots for burners with input of more than 1,000,000 Btu per hour. A suitable flame safeguard should be used so that no gas can flow to the main burner unless satisfactory ignition is assured. On burners with inputs of from 400,000 to 1,000,000 Btu per hour, the response time of the flame safeguard to de-energize the gas shutoff device on flame failure should not exceed 180 seconds. In capacities of more than 1,000,000 Btu per hour, the response time of the aforementioned flame safeguard should not exceed 4 seconds.

The burner assembly should consist of the main burner, pilot burner, automatic valve, the necessary manual valves, and accessory equipment, plus interconnecting pipes and fittings with provision for rigid mounting. The burner should be constructed so that parts cannot be incorrectly located or incorrectly fitted together. Power burners sealed to the walls of incinerators with capacities of more than 100,000 Btu per hour must be supplied with a means of proving air supply before the main gas valve can be energized.

Electrical motors of more than 1/12 horsepower on power burner equipment should be designed for continuous duty and should be provided with thermal overload protection or current-sensitive devices.

When a complete automatic pilot shutoff system is utilized, the controls should be readily accessible and arranged so that the main burner gas can be manually shut off during lighting of the pilot. When a complete automatic pilot system is not utilized, a readily accessible, manually operated, quarter-turn, lever-handle, plug-type valve should be provided to shut off or turn on the gas supply to the main burner manifold. This valve should be upstream from all controls except the pilot control valve.

Clearly defined and complete instructions for lighting and shutting down the burner should be provided in durable, weatherproof material for posting in a position where they can be read easily.

(3) Sizes of Burners Recommended

Where auxiliary burners are used, their capacity range should include the values shown in Table 6.3.5.(8)

Table 6.3.5. GAS BURNER RECOMMENDATIONS FOR GENERAL-REFUSE INCINERATORS

Capacity of incinerator, lb/hr	Size of burners, 10^3 Btu/hr		
	Primary Burners		Secondary Burners
	Type 1 refuse	Type 2 refuse	All refuse
50	150	250	200
100	200	550	300
150	250	650	400
250	300	750	650
500	550	1100	1000
750	750	1500	1300
1000	900	1700	1700
1500	1100	2200	2100
2000	1600	3300	2700

SOURCE: INTERIM GUIDE, Reference 8.

(4) Other Fuels

If natural gas is not available, equivalent amounts of liquid fuels may be used. Fuel oils of grades higher than Number 2, however, should not be used. The National Fire Protection Association Standard No. 31, Installation of Oil Burning Equipment (1965), should be adhered to where oil burners are used.

If liquified petroleum gas is used, burners should be equipped with a device that will automatically shut off the main gas supply in the event the means of ignition becomes inoperative. The arrangement should be such as to shut off the fuel supply to the pilot burner also.

j. Scrubbers (8)

Effluents from general refuse incinerators burning more than 200 pounds per hour should be cleaned in scrubbers to meet particulate limits. Alternate scrubber designs or gas washers should include, as a minimum, the following features:

(1) The scrubber or gas washer should contain sprays, wetted baffles, or orifices arranged singly or in combination so as not to permit the discharge of particulate matter in violation of the Code of Federal Regulations.

(2) Unlined gas washers or scrubbers should have welded or gasketed seams and be corrosion resistant. Lined gas washers or scrubber casings should be made of at least 12-gauge steel and be welded or gasketed. The density of refractory lining should be no less than 120 pounds per cubic foot. The refractory should never be less than 2 inches thick and must be adequately anchored to the casing.

(3) Scrubbers requiring an induced-draft fan should have a motor capable of cold startup (70°F). When the impeller of an induced-draft fan is in the gas stream, the fan must be equipped with a cleanout door and drain.

(4) Where spray nozzles are employed, an optimum spray pattern must be provided to cover all the area of the gases as they

pass through the gas washer or scrubber. Nozzles and valves should be arranged for independent removal by means of unions or flanges. When water is recirculated, a pressure regulator and a strainer should be provided.

(5) An access door for cleanout should be provided on all scribbers.

(6) Interlocks should be provided when induced-draft fans and sprays are used.

(7) When the outside skin temperature of a gas washer or scrubber exceeds 260°F, protection should be provided.

(8) For inside installations, a by-pass arrangement of breeching, or flue connections with dampers, to by-pass the scrubber and induced-draft fan is recommended.

Provision should also be made to supply scrubbing water and a means of disposing of contaminated water from the scrubber. In some areas it will also be necessary to adjust the pH and process the contaminated water through a clarifier to remove fly ash and other collected solids before the water is sewered.

The inspector should check for corrosion caused by the acidic water continuously flowing through the scrubber.

Water-gas mixtures should be retained within the scrubber from 1 to 1-1/2 seconds at gas velocities not exceeding 15 feet per second. The residence time in the scrubber should also be sufficient to vaporize all the water droplets within the effluent gas stream. Complete vaporization is important since nuisance complaints may result from the carryover of water droplets deposited on the surrounding area.

3. General Refuse Incinerators

General refuse incinerators are designed to handle wide ranges of fuel composition (types 0, 1, 2, 3, and 4 wastes), moisture, volatility, diversity in ash content, bulk density, heat of combustion, burning rates and component particle size. General refuse incinerators should be equipped with secondary burners for combustion of Type 0 waste and primary and secondary burners for Types 1, 2, 3, and 4 wastes (See Table 6.3.2). Incinerators with capacities greater than 200 pounds per hour should be equipped with scrubbers.

a. General Operating Procedures

The most important single aspect of operation of a multiple-chamber incinerator is the method of charging the refuse into the ignition chamber.(4) A multiple-chamber incinerator must be charged properly at all times in order to reduce the formation of fly ash and maintain adequate flame coverage of the burning rubbish pile and the flame port. A recommended charging cycle starts with the placing of the initial charge of refuse in the incinerator. The ignition chamber should be filled to a depth approximately two-thirds to three-fourths of the distance between the grates and the arch before lightoff. After approximately half of the refuse has been burned, the remaining refuse should be carefully stoked and pushed as far as possible to the rear of the ignition chamber. New refuse should be charged over the front section of the grates, which have been emptied by the moving of the burning refuse. To prevent smothering the fire, no material should be charged on top of the burning refuse at the rear of the chamber. With this charging method, live flames cover the rear half of the chamber, fill the flame port, and provide nearly complete flame coverage in the mixing chamber. The fire propagates over the surface of the newly charged material, spreading evenly and minimizing the possibility of smoke emissions. Since the refuse pile need not be disturbed unduly, little or no fly ash is emitted.

Characteristic of the multiple-chamber incinerator is that control of air-polluting emissions is built in, if the incinerator is operated with reasonable care. The discharge of combustion contaminants is almost entirely a function of ignition chamber design and the actions of the operator. Control of smoke is attained by proper admission of combustion air and by use of secondary burners in cases of incineration of refuse with a low heating value or high moisture content. The use of secondary burners is required at times since the efficiency of the mixing chamber depends upon both luminous flame and adequate temperatures for vapor phase combustion. The need for supplementary burners may be determined readily by observing the nature of the flame travel and coverage at both the flame port and the curtain wall port.

The overfire and underfire air ports are usually half-open at lightoff and are opened gradually to a full open position as the incinerator reaches its rated burning capacity. If black smoke is emitted, the admission of more secondary air and reduction of the capacity of other air ports are advisible. On the other hand, white smoke is usually the result of a too cold furnace and may be eliminated by reducing or closing all air ports. After the final charge or refuse, the air ports are closed gradually so that during the burndown period the only air introduced into the furnace is provided through leaks around door and port openings.

When ignition and mixing chamber burners are necessary, the mixing chamber or secondary burner is lighted before the incinerator is placed into operation. The burner should remain in operation for the first 15 to 20 minutes of operation and should be used thereafter as needed. Under normal conditions, the ignition chamber or primary burner is used only when wet refuse is charged. At other times, its use, too, may be required when refuse to be burned contains high percentages of inorganic compounds such as clay fillers used in quality paper.

4. Multiple-Chamber Incinerators, Woodworking Industries

Multiple-chamber incinerators used in the woodworking industries are similar in overall design to those used for general refuse purposes, but differ in some important respects. These incinerators must employ super duty plastic or super duty fire clay firebrick refractories and include design factors with respect to secondary chamber cross-sectional areas, inlet air port sizes and other values and proportions which permit higher combustion temperatures arising from the charging of wood products. The gross heating value of kiln dried wood, for example, is about 9000 BTU per pound, and continuous charging of sander dusts and chips from hoggers by mechanical feed systems, further increases combustion temperatures as compared to hand fed general refuse incinerators.

As a consequence, these incinerators must be designed for greater stresses and strains. Adjustment of primary air and the design and operation of the mechanical feeder systems are also important variables in the effectiveness of the incinerator and in the control of emissions. Primary air ports for continuously fed incinerators are sized for induction of theoretical plus 100 percent excess air. Ten percent of the air is admitted through ports located below the grates and 90 percent above the grates. Additional primary air can be admitted by opening the charging door when necessary. If excessively wet refuse is charged in quantity or products such as rubber, oily rags and plastics are significantly charged, secondary burners with automatic controls may be required to maintain high temperatures during all phases of the operation.

Hand charging or intermittent delivery of sawdust (from local exhaust systems serving woodworking) may smother the flames in the ignition chamber and cause smoke. For this reason, continuous feed systems are desirable.

In inspecting woodworking facilities, the inspector should:

- Inventory all local exhaust systems discharging into mechanical feed systems, including the woodworking machines served such as saws, tenoners, sanders, jointers, etc., as well as the diameter of the ducts and number and horsepowers of blowers.
- Establish types of woods employed such as softwoods and hardwoods (e.g., pine wood shavings do not flow as easily as hardwood shavings due to resin content and adhesive properties).
- Check type of surge or feed bins employed in the mechanical feed system. These should be appropriately designed to handle the type and volume of wood wastes. Wood wastes that exhibit poor flow characteristics should be handled in bins constructed with vertical sides and screw or drag conveyors covering the entire flat bottom of the bin. Bins with sloping bottoms may require mechanical agitators or vibrators to prevent bridging.
- Check conveyor systems: Screw conveyors with variable pitch are recommended over screws with uniform pitch because they permit more even loading of the screw along the entire length and thus minimize the compressing of sawdust and shavings causing bridging above the discharge end of the screw. Drag conveyors should be used where long, tough, fibrous shavings are to be conveyed.
- Check pneumatic conveyor system: These should be designed and operated to prevent sawdust from being aspirated into the system faster than the normal delivery rate of the screw.

Conveyors should extend at least three screw diameters beyond the end of the bin and shrouds should be installed over the extended section.

- Check the discharge of wood waste from the pneumatic conveying system to assure that particles are being spread evenly over the entire grate area and to maintain active flame over the surface of the burning pile. The amount of conveying air entering the ignition chamber can be regulated by means of a butterfly damper in the top outlet duct of the cyclone separator, or spiral vanes within the cone of the cyclone.
- Check the cyclone separators: These are usually of the small diameter, high efficiency type. A flap-type damper equipped with a counter balance weight should be installed at the bottom outlet of the cyclone. This damper prevents smoke from being emitted from the cyclone and damage from occurring to the sheet metal construction.

a. General Operating Procedures(9)

Certain differences exist between the operation of wood-burning incinerators and general-refuse incinerators. The operator of a general-refuse incinerator generally relies on auxiliary burners to maintain temperatures for maximum combustion in the secondary chamber. The operator of a woodburning incinerator, without provisions for auxiliary burners, is able to maintain adequate secondary chamber temperatures by proper charging and control of combustion air.

Generous amounts of clean dry paper are mixed with the wood for the initial charge. After the ignition chamber is one-half to two-thirds full, additional paper is placed on top of the pile to ensure quick flame coverage at the surface. It is important, in keeping smoke to a minimum, that only clean dry paper and dry scrap wood comprise the initial charge. After charging is completed, the paper is ignited near the front of the chamber and the charge door is closed. All combustion air ports are almost completely closed to restrict combustion air.

As burning proceeds, the incinerator passes through the most critical period of its operation. By observing the emissions from the stack, the necessary adjustments can be made promptly to reduce or eliminate smoke. Gray or white smoke emitted after lightoff indicates that the incinerator is cold. This smoke can be minimized or eliminated by closing all air ports. Smoke of this color usually ceases within a few minutes after lightoff when flames completely cover the refuse pile and fill the flame port. A few minutes later, black smoke may appear, resulting from a lack of adequate combustion air. These emissions can usually be eliminated by opening primary air ports and then the secondary air ports. If additional combusion air is required, it may be supplied by opening the charge door.

Although each incinerator has its own operating characteristics, the overfire and underfire air ports can usually be opened to 10 minutes after lightoff, and the secondary port, 20 to 30 minutes later. If opening of the secondary ports results in gray or white smoke emissions, the ports should be closed immediately since the incinerator has not yet reached its normal operating temperature.

After attaining normal operating temperatures, maximum combustion is maintained by placing the mechanical feed system in operation or by hand charging at regular intervals.

The refuse is then ignited and, if the refuse is moist, the grate burners are also lighted. The refuse may be stoked frequently to uncover fresh material without fear of creating excessive fly ash emissions because of the draft-limiting action of the damper.

When the refuse has been destroyed, the grate burners are turned off and the grates are cleaned by dumping the ashes into the ash pit. After a brief period of time is allowed to permit smoke from the smoldering ashes to clear, the afterburner is turned off and the draft control damper opened.

The final step, that of unlocking the chute doors, should not be performed until about 10 minutes after the grates have been cleaned. This delay allows the incinerator to cool so that newly charged refuse is not ignited by the residual heat in the incinerator.

The sequence of operation in using a flue-fed incinerator modified with a basement afterburner is the same as that described above.

5. Multiple-Chamber Flue-Fed Incinerators

Examples of single and double by-pass flue multiple-chamber incinerators for apartment houses are shown in Figures 6.3.3 and 6.3.4.(10) These incinerators have the potential for complying with new emission limitations and are far superior to single-chamber incinerators, but improvements in combustion efficiencies are still needed. Consideration also may need to be given to seasonal variations in building pressure of high rise buildings in terms of their effect on gas flow in charging chutes and exhaust flues.

a. General Operating Procedures(11)

Before burning is begun, the solenoid locks on the charging chute doors are actuated and the damper below the breeching is closed.

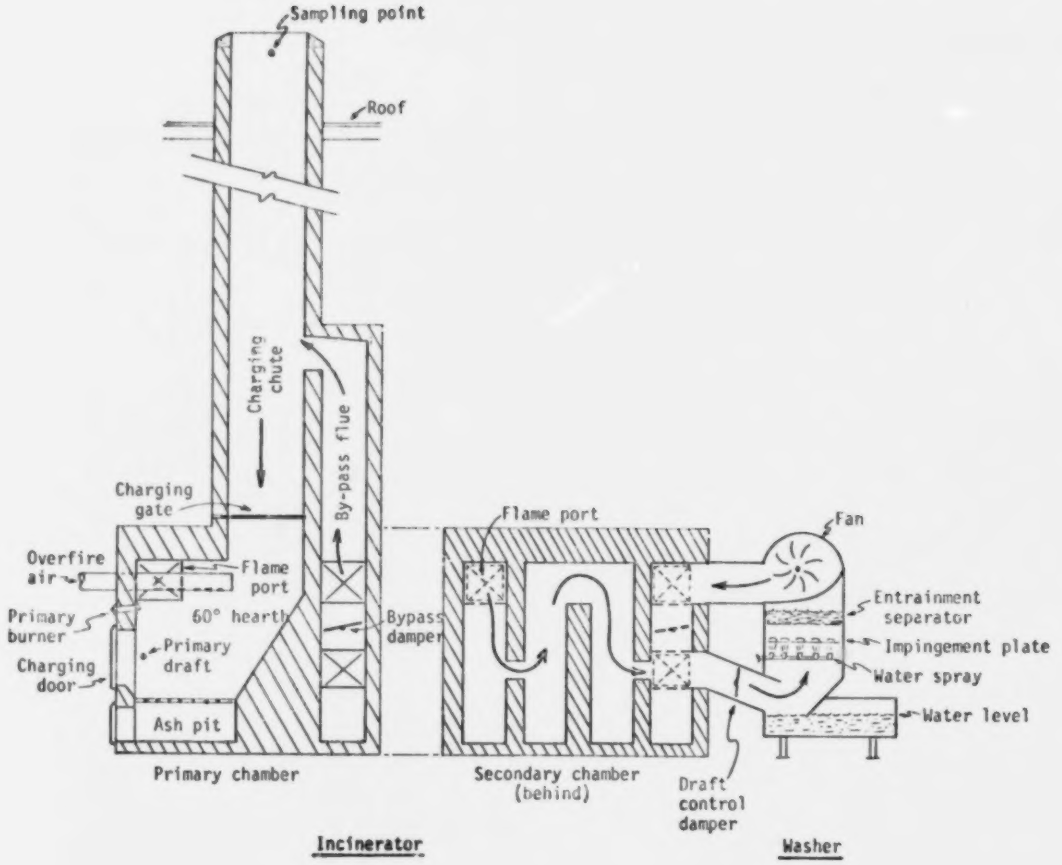

Sampling point
Roof
Charging chute
By-pass flue
Charging gate
Overfire air
Flame port
60° hearth
Primary burner
Primary draft
Charging door
Ash pit
Bypass damper
Primary chamber
Flame port
Secondary chamber (behind)
Fan
Entrainment separator
Impingement plate
Water spray
Water level
Draft control damper
Incinerator
Washer

Figure 6.3.3. MULTIPLE-CHAMBER INCINERATOR WITH SINGLE PASS FLUE
(SOURCE: Sableski, Reference 10)

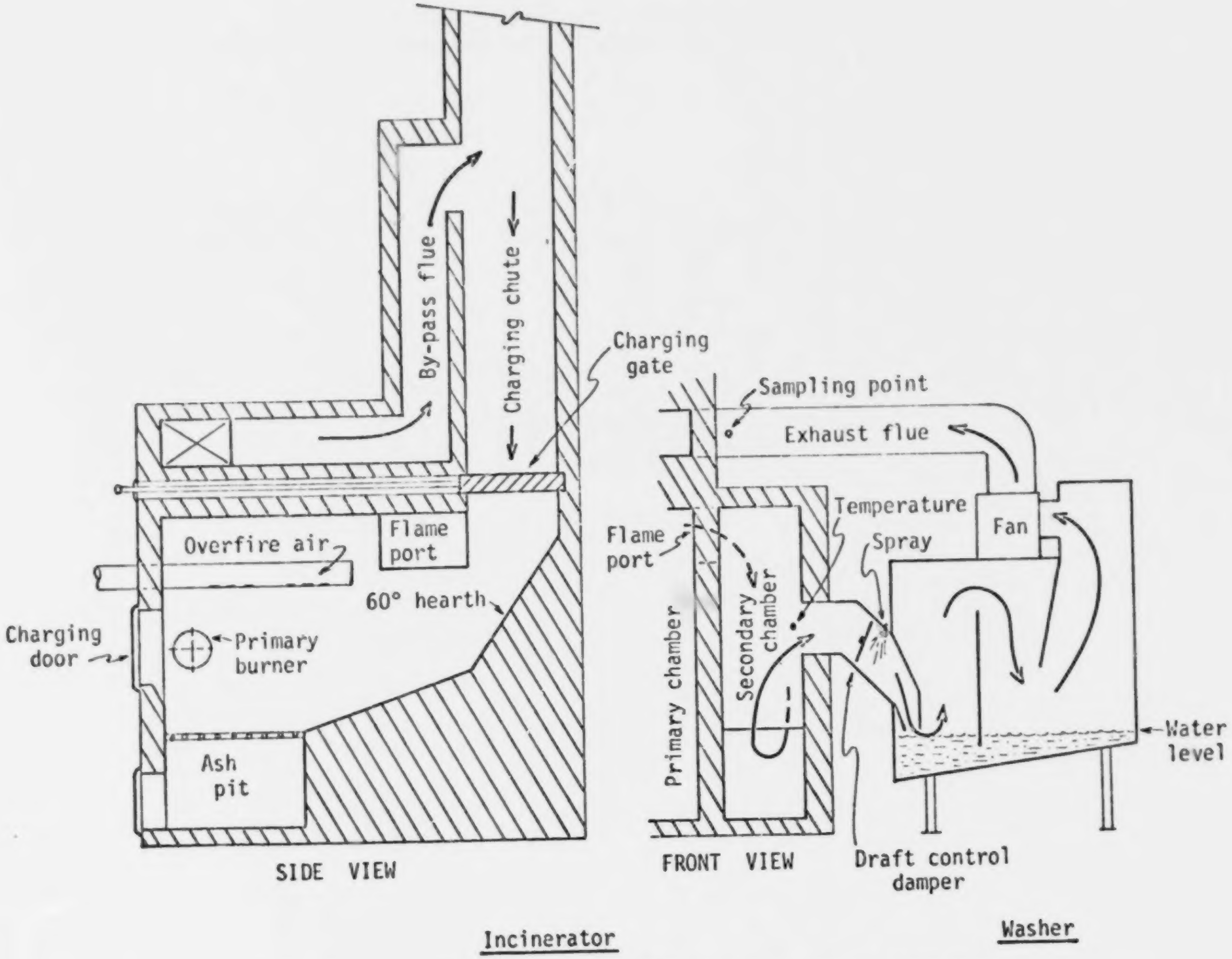

By-pass flue
Charging chute
Charging gate
Flame port
Overfire air
60° hearth
Charging door
Primary burner
Ash pit
SIDE VIEW
Sampling point
Exhaust flue
Temperature
Spray
Fan
Flame port
Primary chamber
Secondary chamber
Water level
FRONT VIEW
Draft control damper
Incinerator
Washer

Figure 6.3.4 MULTIPLE-CHAMBER INCINERATOR WITH DOUBLE PASS FLUE
(SOURCE: Sableski, Reference 10).

The mixing chamber burners of the incinerator are then ignited. The ignition chamber burners are also ignited if the refuse is of low heating value or high moisture content. The charging and operation of the incinerator are similar to General Refuse Incinerators described above. Burning is usually carried out once a day, since the bin does not normally provide storage for much more than that length of time. When burning is completed, the incinerator burners are turned off, the doors to the bin are closed, the flue damper is opened, and the chute doors unlocked.

The sequence of operations performed in using a flue-fed incinerator, modified with afterburners, starts with the locking of the chute doors from the main switch in the basement. The draft control damper is closed and the afterburner ignited by remote control from another switch also located in the basement.

D. SINGLE-CHAMBER INCINERATORS

Single chamber incinerators are devices in which one chamber serves ignition, combustion and ash removal, partitioned only by a fixed or movable grate. Since this type of incinerator fails to provide the conditions necessary for complete combustion--it is quite often nothing more than an enclosed open fire--the control of smoke, volatilized gases and fly ash in its operation is uncertain. Single-chamber incinerators inherently do not meet current or proposed particulate, opacity or other emission limitations and should be prohibited. While they can be improved by means of auxiliary equipment, design modifications and control devices (such as afterburners), the results are frequently questionable. The cost of modifying a single-chamber incinerator may be equivalent to the cost of installing a multiple-chamber incinerator in many cases.

While the use of single-chamber incinerators is declining, field officers in some communities will be inspecting these incinerators. Their primary objective will be to (1) seek abandonment of single-chamber incineration in favor of disposal in cut-and-cover dumps or multiple chamber incinerators or (2) to assure that such incinerators are being properly operated and maintained to meet all emission standards. Inspectors should be familiar with the following types of single-chamber incinerators:

1. General Residential and Commercial

   Small residential concrete slab or brick construction, box-type or Dutch oven types, or improvised or homemade equipment made from drums, etc., in which provisions are made for charging and clean-out doors, stacks and air supply. Operation of these incinerators should not be prohibited.

2. Flue-Fed Incinerators

   The operation of flue-fed incinerators may be additionally complicated by (1) the method of charging; (2) the number of users; and (3) excessive draft conditions due to tall flues, particularly in high buildings.

   Since the charging method consists of depositing of rubbish into the flue through chute doors located at the various floors of the dwelling unit, rubbish material can block flues causing excessive smoke from the stack and leakage of smoke through chute doors, or smothering of the fire. Random charging by residents results in poor control of burning conditions.

   In these types of incinerators the type of refuse burned is related to the number and types of apartments rented. If food is prepared on the premises, the refuse will contain a high quantity of plastics, waxed cartons and non-combustibles.

   Excessive draft conditions in tall flues also result in cooling the fire, causing incomplete burning particularly of combustible gases, oils, tars and fats usually contained in the refuse pile. Draft, and the incinerator conditions it causes, increase with stack height. Fly ash emissions are also increased by stoking refuse piles. Operation of this type of incinerator(11) can be improved by the following types of modifications:

- Installation of solenoid locks on each of the chute charging doors. Locks can be actuated from a single switch in the basement before the stack damper is closed and the burning cycle begins.
- An air tight unit is essential if combustion air is to be controlled. Particular attention should be paid to cracks which occur with age and use, and to relatively large openings around chute doors.
- Installation, where none exists, of dampers in the stack to control stack drafts and to achieve desired combustion temperatures. Swinging, counter-weighted dampers are effective and are usually located in the flue beneath the first floor chute door to ensure a negative pressure at each door and thus prevent smoke and sparks from blowing by the chute doors into the buildings. Automatic draft control dampers are preferred in most installations.
- Installation of double flues; one for charging refuse and one for exhaust of products of combustion are desirable.
- Auxiliary gas burners under grates to further promote drying of refuse is desired.
- Installation of a gas washer for particulate collection or afterburner for elimination of smoke, odors and fly ash is desirable. Afterburners may be either direct-fired or catalytically fired, usually the former. Afterburners can be located either in the stack on the roof of the apartment house or at

the base of the flue in the basement. Figures 6.3.5 through 6.3.7 are examples of modified afterburner installations.(11) Figure 6.3.8 is a schematic of a modified single-chamber flue-fed incinerator that includes a separate exhaust flue, gas washer, moving grates and other control and automatic features.(10) The effectiveness of any modifications in any given installation, however, may be of questionable value since constant observation and frequent source testing will be required to assure compliance with incinerator regulations.

3. Wood Waste-Burning Incinerators

Wood waste-burning incinerators include wigwam burners and silo incinerators used in connection with the lumber and woodworking industries. These are usually of metal construction, refractory lined or unlined, are fed continuously or intermittently by cyclone, hogger, moving grates, or by hand. Many enforcement agencies are prohibiting the construction of these types of incinerators.

Silo incinerators are large cylindrical incinerators used mostly in connection with woodworking and furniture manufacturing industries. Wigwam incinerators are of round construction and taper towards the top, and are used primarily for the disposal of wood and bark residue from the lumbering industry. Generally, these incinerators do not employ grates and tend to have an underfire air problem. Overfire air can be regulated by port openings located around the base of the burner. Because of the large capacities of these incinerators and the commitment to them on the part of industry, most efforts to control emissions from this source are concentrated in the modification of fuel feed systems. Figures 6.3.9 and 6.3.10 illustrate typical wigwam burners with various fuel feed and dryer systems.(12)

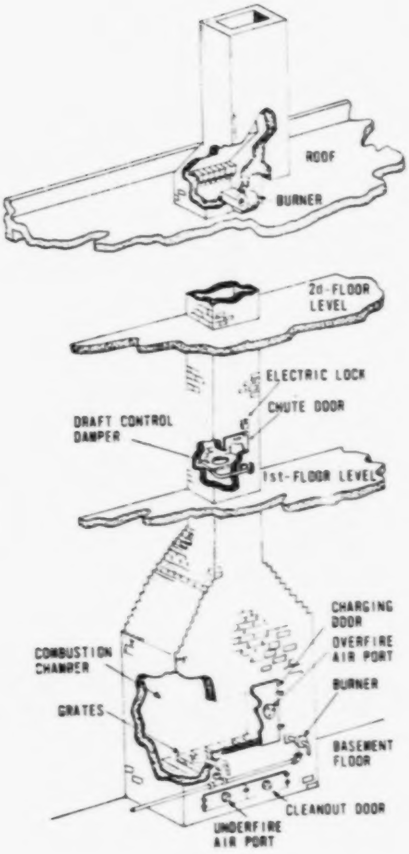

ROOF
BURNER
2d-FLOOR LEVEL
ELECTRIC LOCK
CHUTE DOOR
DRAFT CONTROL DAMPER
1st-FLOOR LEVEL
CHARGING DOOR
OVERFIRE AIR PORT
COMBUSTION CHAMBER
BURNER
GRATES
BASEMENT FLOOR
CLEANOUT DOOR
UNDERFIRE AIR PORT

Figure 6.3.5. FLUE-FED INCINERATOR MODIFIED BY A ROOF AFTER-BURNER AND A DRAFT CONTROL DAMPER
(SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 11.)

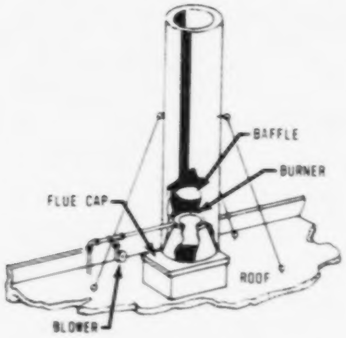
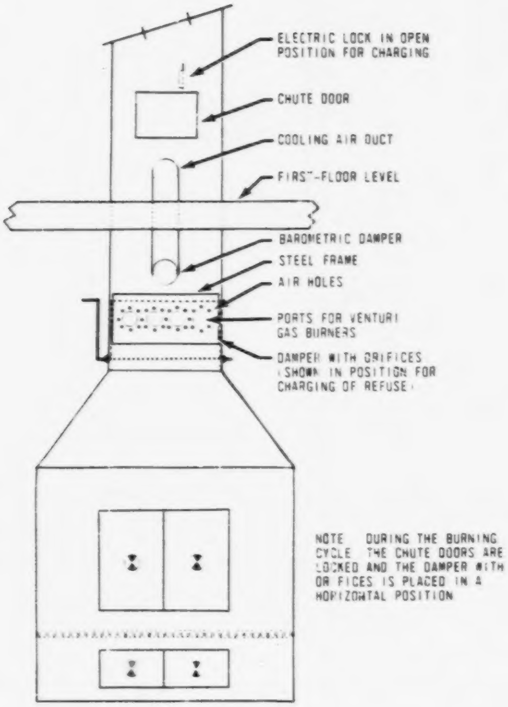

BAFFLE
BURNER
FLUE CAP
ROOF
BLOWER

Figure 6.3.6. FLUE-FED INCINERATOR MODIFIED BY A ROOF AFTER-BURNER, AND A DRAFT CONTROL DAMPER
(SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 11.)


ELECTRIC LOCK IN OPEN POSITION FOR CHARGING
CHUTE DOOR
COOLING AIR DUCT
FIRST-FLOOR LEVEL
BAROMETRIC DAMPER
STEEL FRAME
AIR HOLES
PORTS FOR VENTURI GAS BURNERS
DAMPER WITH ORIFICES (SHOWN IN POSITION FOR CHARGING OF REFUSE)

NOTE DURING THE BURNING CYCLE THE CHUTE DOORS ARE LOCKED AND THE DAMPER WITH ORIFICES IS PLACED IN A HORIZONTAL POSITION

Figure 6.3.7. FLUE-FED INCINERATOR MODIFIED BY AN AFTERBURNER AT THE BASE OF THE FLUE
(SOURCE: AIR POLLUTION ENGINEERING MANUAL, Reference 11.)

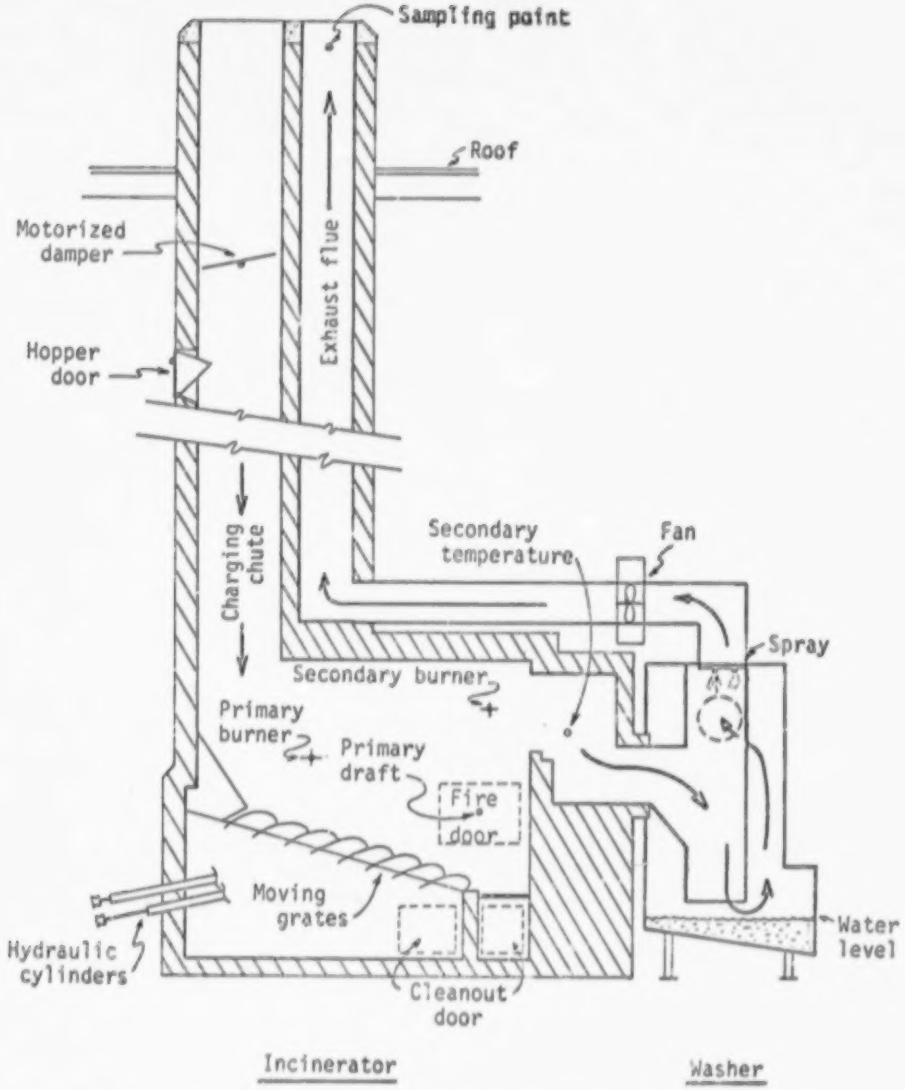

Sampling point
Roof
Motorized damper
Hopper door
Exhaust flue
Charging chute
Secondary temperature
Fan
Spray
Secondary burner
Primary burner
Primary draft
Fire door
Moving grates
Hydraulic cylinders
Cleanout door
Water level
Incinerator
Washer

Figure 6.3.8. MODIFIED SINGLE-CHAMBER FLUE-FED INCINERATOR, 360 POUNDS PER HOUR CAPACITY (SOURCE: SABLESKI, et al., Reference 10.)

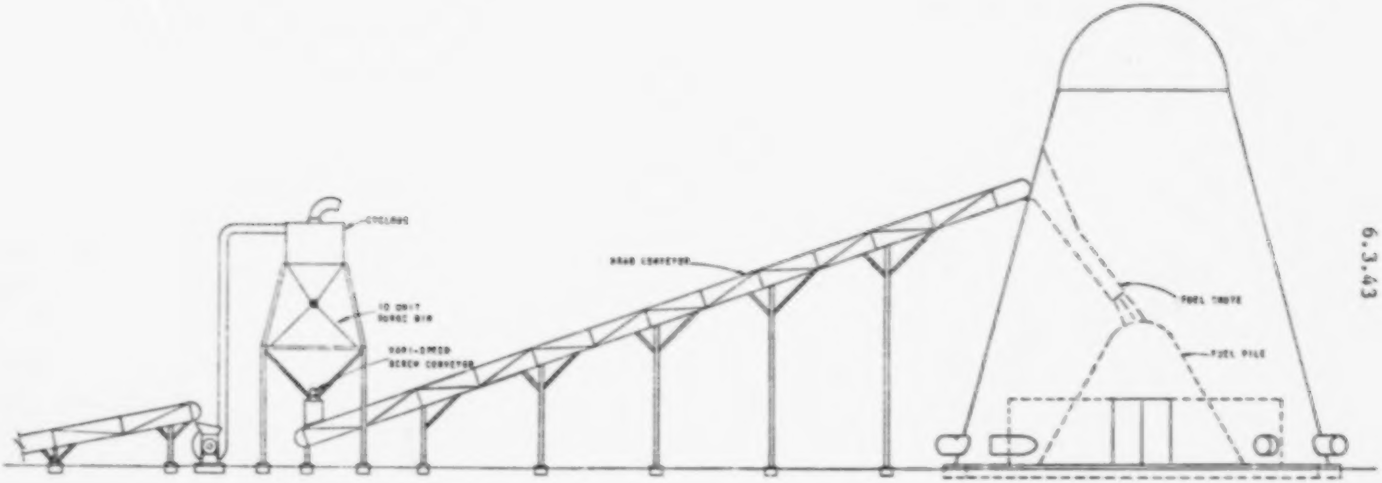

CYCLONE
10 UNIT
SURGE BIN
VARI-SPEED
SCREW CONVEYOR
DRAG CONVEYOR
FUEL CHUTE
FUEL PILE

Figure 6.3.9. FUEL FEED SYSTEM OF A WIGWAM BURNER
(SOURCE: CORDER, et al., Reference 12.)

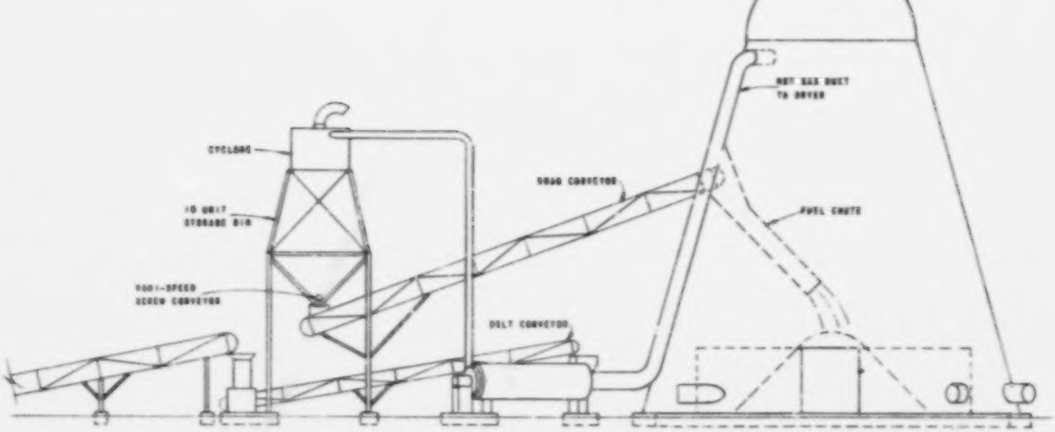

CYCLONE
10 UNIT STORAGE BIN
VARI-SPEED SCREW CONVEYOR
DRAG CONVEYOR
BELT CONVEYOR
HOT GAS DUCT TO DRYER
FUEL CHUTE

Figure 6.3.10. FUEL FEED AND DRYER SYSTEM OF A WIGWAM BURNER
(SOURCE: CORNER, et al., Reference 12.)

4. General Operating Procedures and Inspection Points - Single-Chamber Incinerators

It is difficult to generalize good operating guides for all classes of single chambers, for all designs, refuse types and uses. These must be established in each case by:

- Control over moisture, constituents and mixtures of refuse charged.
- Adjusting ignition procedures with respect to air supply (opening of charging doors, underfire air ports or supply, setting dampers, etc.), size of refuse pile, positioning of refuse pile and use of kindling materials.
- Closing or adjusting charging and ash pit doors, or underfire and overfire spinners, for appropriate air supply throughout the burning cycle.
- Stoking of burning pile, particularly near the end of the burning period, by grate manipulation and use of stoking implement. Stoking action should be gentle to avoid fly ash emissions.
- Use of underfire or overfire gas firing system.
- Maintaining free draft passages, e.g., regular removal of ash from ash chambers and avoidance of blockages of chutes and grates.

Single-chamber incinerators should be in frequent or constant attendance and appropriate adjustments to the combustion system should be made whenever smoke or fly ash occurs. The color of the smoke is generally an indicator of the type of problem that must be remedied. Black smoke suggests a deficiency of air in relation to the volume and composition of the material being burned. Material with high organic or carbon content may tend to burn black. White smoke indicates that combustion temperatures are too low. This is usually due to too much excess air or moisture in the refuse. A fly ash problem may result from excessive air supply--particularly underfire air--and uneven mixtures of light and heavy materials (e.g., paper products and saw dusts), defective spark arrestor, excessively short stack and poor damper control. In general, low excess air is preferred in lessening smoke and particulate emissions.

E. MUNICIPAL INCINERATORS

Municipal incinerators are designed to dispose of combustible wastes collected from residential, commercial and industrial sources that have been transported to the incinerator site. The principles of combustion of solid waste--especially primary and secondary combustion treated in the previous parts of this section--also apply to municipal incinerators. However, the operation of these incinerators involves a number of additional considerations associated with the scale and complexity of the operation that the inspector should take into account.(7)

- Combustion of an equivalent amount of refuse in municipal incinerators is more efficient and results in less air pollution, than burning of refuse by individuals in open fires and small incinerators, particularly single-chamber incinerators.
- The municipal incinerator, like a large steam-generating station, constitutes a large concentrated source of air pollution, which may not only fail to comply with local particulate and Ringelmann regulations, but may create a public nuisance in terms of odors, dust, noise and unsightliness. The stacks from such incinerators are usually visible from many miles away.
- Other air pollution and environmental problems are presented by municipal incinerators in addition to stack effluents. These include odors from putrefaction of organic material present in the effluent and stored refuse, dusts from truck traffic and material handling, water and land pollution problems from residue

quenching and water treatment procedures and insect and rodent problems, as summarized in Figure 6.3.11.(7)

Small municipal incinerators are those which range in size from 50-100 tons per day (TPD) capacity. Large incinerators may exceed 1000 TPD in capacity. Fly ash emissions from municipal incinerators may vary from 8 to 70 lb. per ton of solid waste burned, without control equipment. Sulfur oxide emissions run approximately 1.5 lbs. per ton of waste as fired. Most of the sulfur is further retained in the ash. Oxides of nitrogen emissions are on the order of 2 lbs. per ton of waste, which is approximately ten times less than from fuel combustion due to the generally lower Btu value of solid waste fuel, although, the heat value of solid waste fuel appears to be increasing. Hydrogen chloride (HCL) emissions may be of concern because of the toxicity of this contaminant to the eyes and respiratory system. HCL emissions result from plastic polyvinyl chloride found in increasing amounts in municipal solid waste. The gas is highly soluble in water and can probably be effectively removed with water scrubbers.

The design of municipal incinerators should be based on the waste characteristics and current and projected waste volumes of the community being served. The composition, moisture, heating value and specific materials contained in the solid waste will vary by community. Household wastes will differ from food wastes from stores and restaurants and from the relatively dry high-heat-value waste generated from industry. Factors that must be considered in the design of the incinerator system include furnace chamber, grates, feed mechanisms and refractories. Procedures for sampling and analysis of solid waste have been published by the American Public Works Association.(13) Oxygen bomb calorimetry for determining the amount of heat liberated from solid materials and liquids are also described.(14)

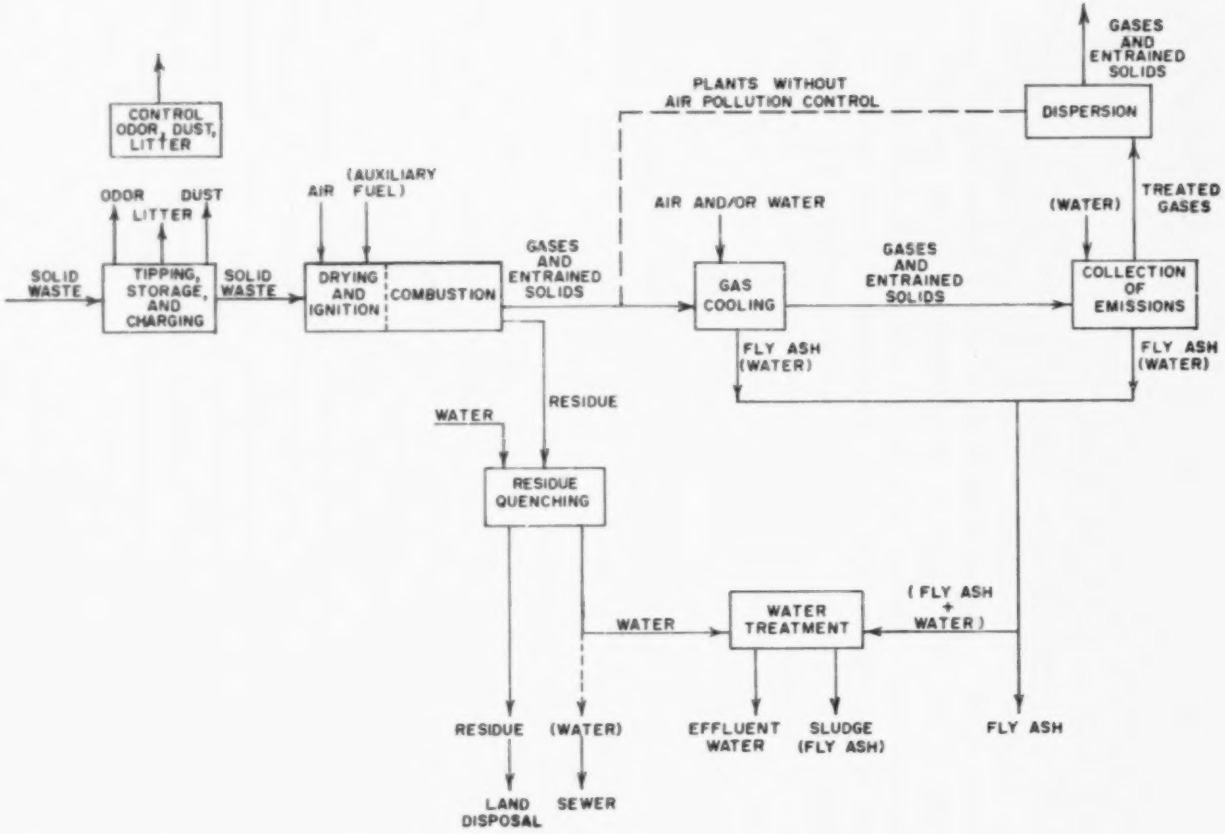

CONTROL ODOR, DUST, LITTER
ODOR
LITTER
DUST
SOLID WASTE
TIPPING, STORAGE, AND CHARGING
SOLID WASTE
AIR
(AUXILIARY FUEL)
DRYING AND IGNITION
COMBUSTION
GASES AND ENTRAINED SOLIDS
PLANTS WITHOUT AIR POLLUTION CONTROL
AIR AND/OR WATER
GAS COOLING
GASES AND ENTRAINED SOLIDS
(WATER)
COLLECTION OF EMISSIONS
TREATED GASES
DISPERSION
GASES AND ENTRAINED SOLIDS
FLY ASH (WATER)
FLY ASH (WATER)
RESIDUE
WATER
RESIDUE QUENCHING
WATER
WATER TREATMENT
(FLY ASH + WATER)
RESIDUE
(WATER)
EFFLUENT WATER
SLUDGE (FLY ASH)
FLY ASH
LAND DISPOSAL
SEWER

Figure 6.3.11. DIAGRAM OF THE INPLANT SYSTEMS BASED UPON DRY FLY ASH COLLECTION AND CONVEYING FROM COOLING AND COLLECTION OPERATIONS. ALTERNATIVES FOR WET COLLECTION AND CONVEYING SHOWN IN PARENTHESES (SOURCE: DEMARCO, et al., Reference 7.)

Bulky combustible items, such as furniture and fixtures, as well as flammable, toxic, radioactive, organic, pathological or putrescible residues may present special problems.

A flow chart of the overall operation of municipal incinerators is shown in Figure 6.3.11. Municipal incinerators operations that may be of concern to the inspector include:

- Delivery and Weighing of Solid Waste and Residue. Trucks transporting solid wastes are weighed at the plant to establish the weight of solid wastes being handled by the incinerator, and the weight of ash residue removed from the incinerator. These data are used to improve operation, to assist management control, to facilitate planning and to provide an equitable basis for assessing fees. From an air pollution standpoint, this information is useful in rating the effective capacity of the incinerator, and to test air pollution control devices. A number of different types of scales varying from simple beam scales to electronic relay scales are in use. These have varying degrees of accuracy, depending on plant size and age. Incinerators with a capacity of 100 or more tons per day will generally require two or more scales. The most accurate and most secure system of establishing net weights is through a two-scale system with fully controlled access. One scale weighs in the loaded vehicles, the other weighs out the empty vehicles.
- Shredders and Grinders. The use of shredders and grinders in the handling of bulky wastes should be noted.
- Tipping Area and Storage Pits. (Figure 6.3.12) After being weighed, trucks move on to the tipping area which is adjacent to the storage pits or charging hoppers. At large installations trucks unload into a storage pit, whereas in small incinerators the waste is dumped directly into the furnace charging hopper or onto the tipping floor. If the

tipping floor is not enclosed, this area can be a major source of dusts, odor and noise, particularly during periods of peak traffic. Accidental fires also can be started in the storage pit, thus providing a source of uncontrolled combustion emissions. The inspector should check to assure that dewatering facilities are available for quantities of water that may be necessary in fire fighting. Portable pumps should also be available for removal of excess water.

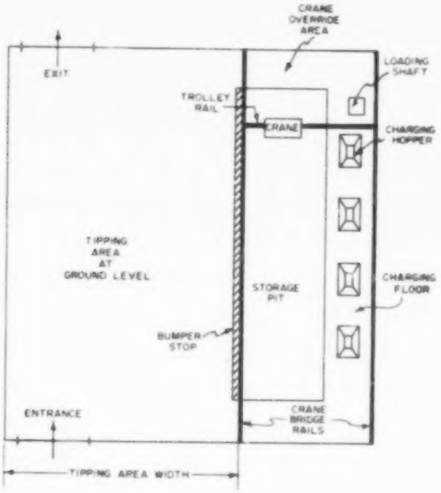

CRANE OVERRIDE AREA
EXIT
LOADING SHAFT
TROLLEY RAIL
CRANE
CHARGING HOPPER
TIPPING AREA AT GROUND LEVEL
STORAGE PIT
CHARGING FLOOR
BUMPER STOP
ENTRANCE
CRANE BRIDGE RAILS
TIPPING AREA WIDTH

Figure 6.3.12. PLAN OF TIPPING AREA AND STORAGE PITS WITH CRANE (SOURCE: DEMARCO, *et al*., Reference 7.)

Storage pits are usually rectangularly shaped. Some pits are divided into separate rectangular units with charging hoppers between units. The storage pit is usually designed to contain about 15 times the 24-hour capacity of the incinerator.

Scattering of dust and litter from dumping, recasting and charging operations is a common problem at municipal incinerators and provision should be made for cleaning the tipping area. Vacuum cleaning facilities and compressed air system for cleaning electrical contacts, powered mobile sweepers and flushers can be used in controlling dust and litter.

An adequate drainage system should also be available to accommodate the wash waters. The inspector should check the size of the receiving sewer.

- Charging Methods. Front-end loaders, vibrating hoppers, conveyors and other mechanical means are used in small installations to transfer and charge the solid waste, where the storage area is on the same elevation as the charging hoppers. At larger installations, cranes are employed.

  Waste is charged to the furnace under gravity or with the assistance of reciprocating or vibrating feed mechanisms through charging chutes. In batch-feed furnaces a gate separates the charging hopper from the furnace and supports the solid waste while the furnace is burning the previous charge. Generally, one hopper is provided for each furnace cell. In a continuous-feed furnace, the waste filled hopper and chute assist in maintaining an air seal to the furnace as well as to provide a continuous supply of solid waste. The inspector should note whether arching of oversized material occurs across the hopper bottom, or whether clogging occurs in the chutes, as these conditions can effect furnace operation and hence emissions. Chutes constructed of smooth surfaces, corrosion-resistant materials and vertical or nearly verticle and increasing cross section design are preferred.

- Furnace Categories. Municipal incinerator furnaces fall into the following categories:

  a. Rectangular. (Figure 6.3.13) In this furnace two or more grates are arranged in tiers so that the moving solid waste is agitated as it drops from one level to the next.

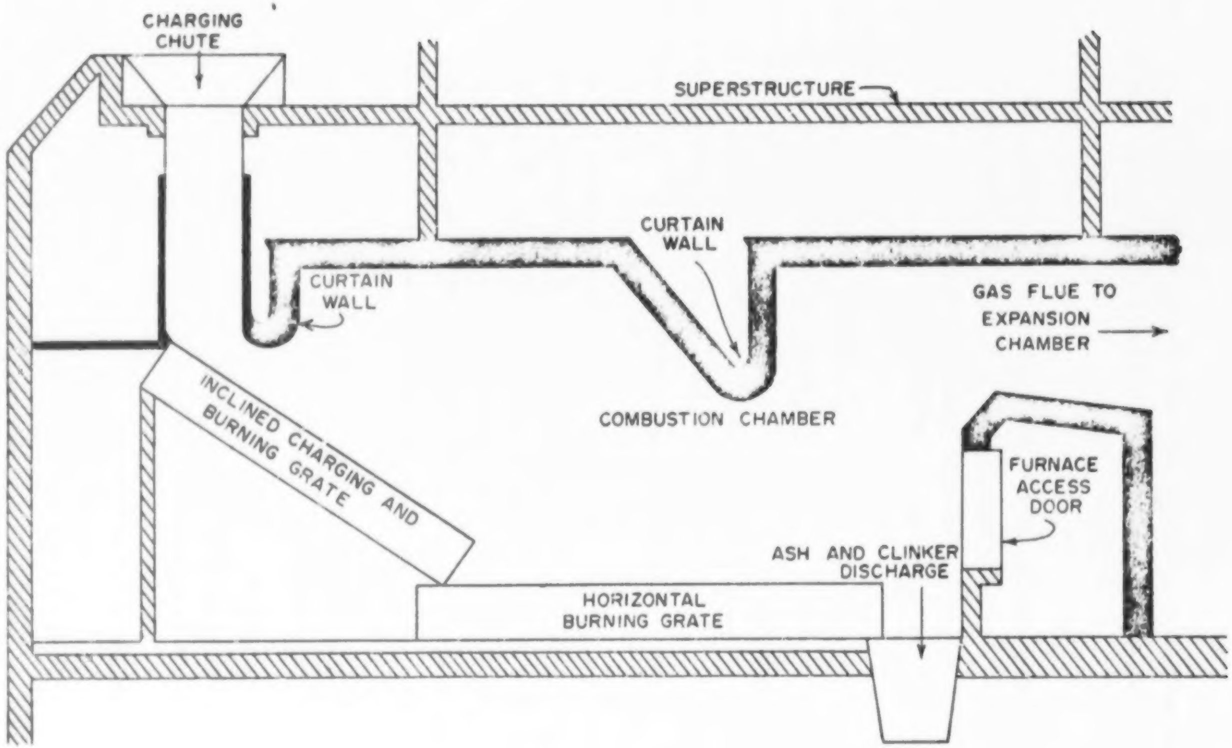

CHARGING CHUTE
SUPERSTRUCTURE
CURTAIN WALL
CURTAIN WALL
GAS FLUE TO EXPANSION CHAMBER
INCLINED CHARGING AND BURNING GRATE
COMBUSTION CHAMBER
FURNACE ACCESS DOOR
ASH AND CLINKER DISCHARGE
HORIZONTAL BURNING GRATE

Figure 6.3.13. RECTANGULAR FURNACE
(SOURCE: DEMARCO, et al., Reference 7.)

b. Vertical Circular Furnace. (Figure 6.3.14) In this furnace waste drops onto a central cone grate and surrounding circular grate. The fuel bed is agitated by means of a slowly rotating cone with arms. Underfire forced air is the primary combustion air, which also serves to cool the grates. Manual agitation and assistance in residue dumping is required, and stoking doors are provided for this purpose. Overfire air is usually introduced to the upper portion of the circular chamber.

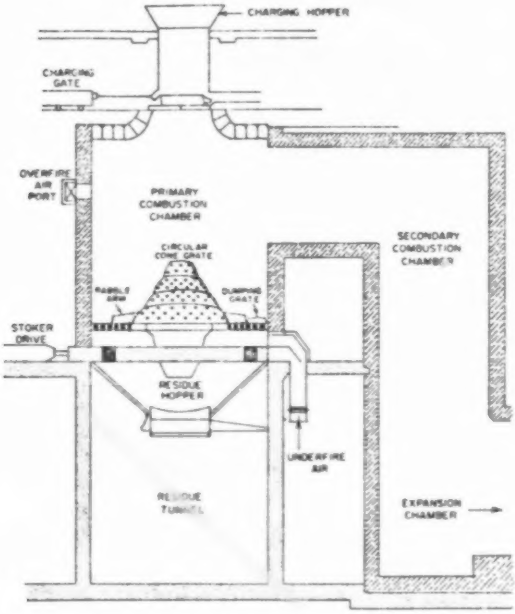

CHARGING HOPPER
CHARGING GATE
OVERFIRE AIR PORT
PRIMARY COMBUSTION CHAMBER
CIRCULAR CONE GRATE
RABBLE ARM
DUMPING GRATE
SECONDARY COMBUSTION CHAMBER
STOKER DRIVE
RESIDUE HOPPER
UNDERFIRE AIR
RESIDUE TUNNEL
EXPANSION CHAMBER

Figure 6.3.14. VERTICAL CIRCULAR FURNACE (SOURCE: DEMARCO, et al., Reference 7.)

c. Multicell Rectangular Type (Mutual Assistance Furnace). (Figure 6.3.15) This type of furnace, which may be refractory-lined or water cooled, is constructed of two or more cells set side-by-side. The cells of the furnace usually have a common secondary combustion chamber and share a residue disposal hopper.

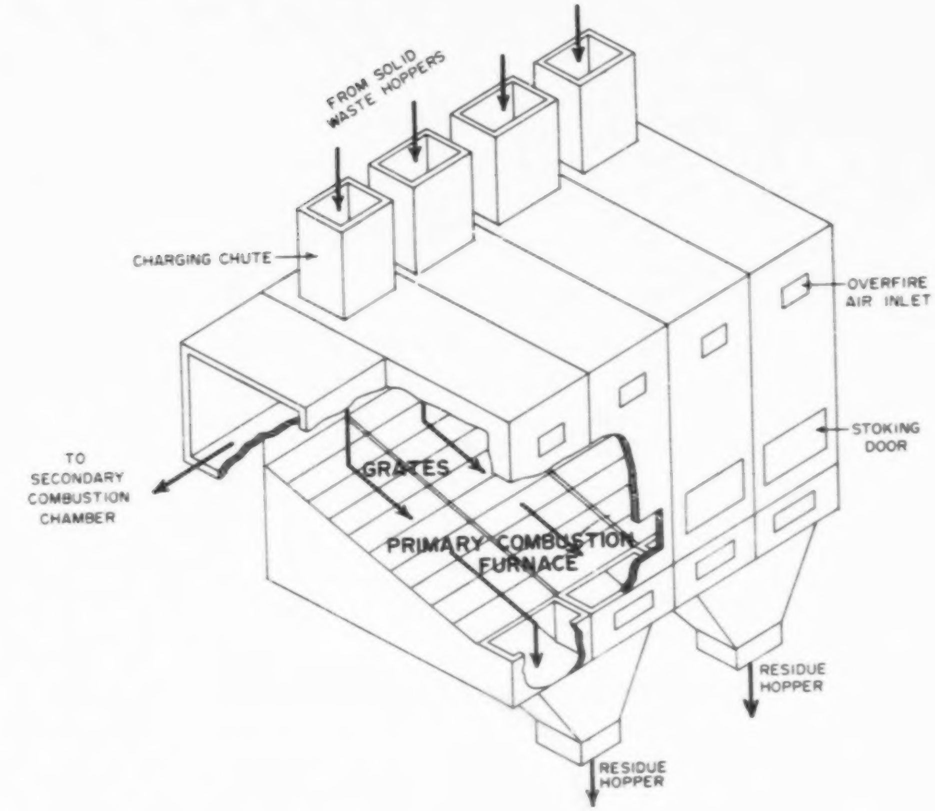

FROM SOLID WASTE HOPPERS
CHARGING CHUTE
OVERFIRE AIR INLET
TO SECONDARY COMBUSTION CHAMBER
GRATES
STOKING DOOR
PRIMARY COMBUSTION FURNACE
RESIDUE HOPPER
RESIDUE HOPPER

Figure 6.3.15. MULTICELL RECTANGULAR FURNACE (SOURCE: DEMARCO, et al., Reference 7.)

d. Rotary Kiln Furnace. This consists of a slowly revolving inclined kiln following a rectangular furnace where drying and partial burning occurs (Figure 6.3.16). The partially burned waste is fed by the grates into the kiln where cascading action exposes combined material for combustion. Final combustion of the combustible gases and suspended combustible particulates occurs in the mixing chamber beyond the kiln discharge. The residue falls from the end of the kiln into a quenching tank.

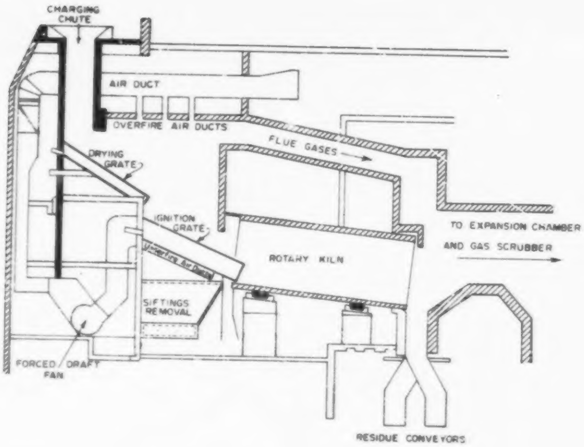

CHARGING CHUTE
AIR DUCT
OVERFIRE AIR DUCTS
FLUE GASES
DRYING GRATE
IGNITION GRATE
Underfire Air Ducts
ROTARY KILN
TO EXPANSION CHAMBER AND GAS SCRUBBER
SIFTINGS REMOVAL
FORCED DRAFT FAN
RESIDUE CONVEYORS

Figure 6.3.16. ROTARY KILN FURNACE
(SOURCE: DEMARCO, et al., Reference 7.)

A variety of grate systems are used in municipal incinerators to accomplish drying, ignition, burning and dumping of ash and residue into residue hoppers. These include traveling, reciprocating, rocking, rotary kiln, circular, vibrating, oscillating and reverse reciprocating grates; multiple rotating drum, rotating cones with arms, and variations or combinations of these. Examples of grates are shown in Figures 6.3.17 through 6.3.20.

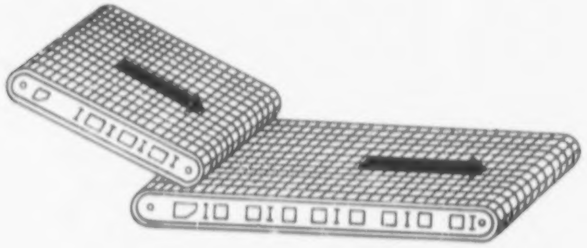


Figure 6.3.17. TRAVELING GRATES (SOURCE: DEMARCO, *et al.*, Reference 7.)

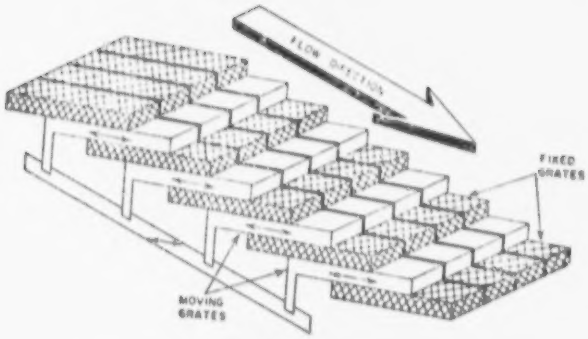


Figure 6.3.18. RECIPROCATING GRATES (SOURCE: DEMARCO, *et al.*, Reference 7.)

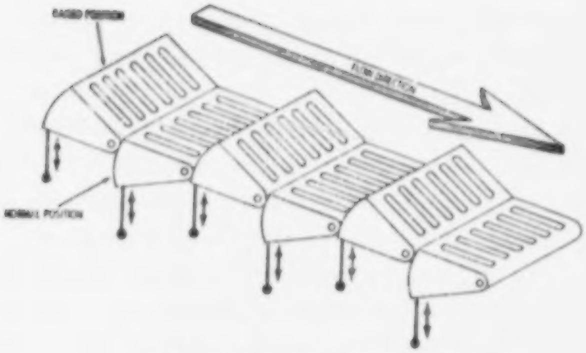

RAISED POSITION
FLOW DIRECTION
NORMAL POSITION

Figure 6.3.19. ROCKING GRATES
(SOURCE: DEMARCO,
et al., Reference 7.)

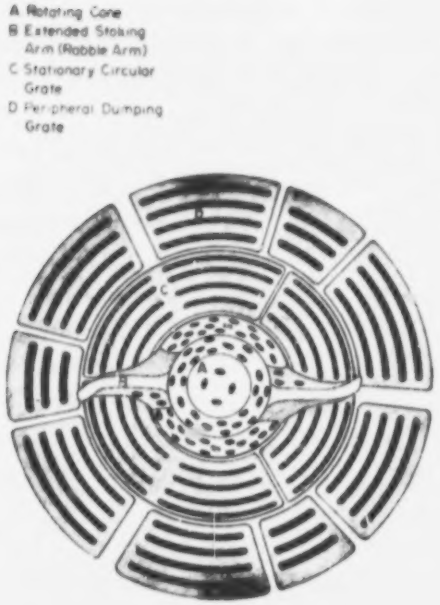

A Rotating Cone
B Extended Stoking Arm (Rabble Arm)
C Stationary Circular Grate
D Peripheral Dumping Grate
A
C
D

Figure 6.3.20. CIRCULAR GRATES
(SOURCE: DEMARCO,
et al., Reference 7.)

The grate systems perform two essential functions: (1) agitation of the refuse to promote combustion by means of tumbling and dropping of the refuse from one grate tier to the next; and (2) passage for underfire air. The inspector should note whether abrupt or excessive tumbling occurs and if excessive amounts of particulates are being emitted. Inert materials, such as glass bottles and metal cans will aid combustion by enhancing porosity of the fuel bed, although they may inhibit combustion by clogging the grate openings. The mechanical condition of the grate system should be checked, where possible, for misalignment of moving parts, bearing wear and warping or cracking of castings due to high temperatures, thermal shock, abrasion, wedging clogging and heavy loads.

The inspector should attempt to determine if siftings are burning beneath the grates. These are fine materials which fall through the fuel bed and may consist of combustible materials such as oil, plastics and grease.

The inspector should note the residue removal operation and method of disposal. Residue usually consists of ash, clinkers, tin cans, glass, rock and unburned organic substances. The residue is dumped from the residue hoppers into trucks or other containers and quenched. Wet, dripping trucks can create a nuisance. In many continuous-feed operations the residue is discharged into water filled troughs, and a slow moving drag conveyor discharges the residue to a holding hopper or directly into a truck. The quench water is allowed to drain from the system before discharge to truck or hopper. This water may be highly abrasive and corrosive.

The following operational guides and inspection points should be noted during inspections of municipal incinerators.

- For most municipal incinerator designs, underfire air is from 40 to 60 percent of total air (underfire, overfire, infiltration).
- A minimum of 50 percent excess air is usually necessary to complete combustion and to promote turbulence: In general, refractory furnaces require 150 to 200 percent excess air, whereas water tube wall furnaces require only 50 to 100 percent excess air.
- Temperatures of burning gases generally range from 2,100 to 2,500°F and for short periods of time may reach 2,800°F in localized areas Combustion air may be preheated to 200 to 300°F. Gas temperatures are between 1,400 and 1,800°F exiting the combustion chamber, and 1000°F or less entering the stack. Gases should be cooled to 500 to 700°F before entering the air pollution control equipment. If heat exchangers are used, gas volumes are reduced, thus reducing requirements for collection devices, fans and gas passages. Excessively high temperatures will increase NO_x emission rate, and cause refractories to fail and slag to buildup on furnace linings.
- When starting a municipal incinerator, operation temperatures of 1,400 to 1,800°F should be reached quickly, consistent with good practice. Incinerators with induced draft fans usually reach operating temperatures in less than one hour. Natural draft plants may require more than four hours. Plants with suspended wall construction require as little as half an hour for heating refractories.
- Auxiliary fuels are desirable to warm the furnace, dry solid waste that is wet or has low BTU content, complete secondary combustion--for odor and smoke control--and to supplement heat for heat recovery units.
- Height and diameter of incinerator stacks depend upon the amount of draft required and topographic and climatic conditions. Induced draft fans should be used to supplement the natural draft in moving gases

through the incinerator. Dampers are generally used in both natural draft stacks and in stacks employing induced draft fans of constant speed. Adjustable speed, induced draft fans are also used to control draft.

Instrumentation and controls are used in municipal incinerators to assess performance, safety, and to prevent pollution. Instruments and automatic controls which monitor and regulate performance are important in the actual control of air pollution from the incinerator. For example, gas temperatures in the furnace are often controlled by increasing or decreasing the amount of underfire and overfire air. Some automatic control systems not only adjust the amount of overfire air, but also adjust the amount of underfire air needed to maintain a specific ratio with the overfire air. Instruments and controls can be used to maintain a steady, high temperature in the secondary combustion zone to assure that odor-producing organic matter in the gas stream is completely oxidized to innocuous compounds. Furnace draft necessary to maintain proper negative pressure in the furnace can be controlled manually or automatically by adjustment of the induced fan and the chimney draft. Draft pressures should be measured at the (1) underfire air duct; (2) overfire air duct; (3) stoker compartments; (4) sidewall air duct; (5) sidewall low furnace outlet; (6) dust collector inlet and outlet (pressure differential); and (7) induced draft fan inlet. Many instruments need frequent calibration to ensure accurate and reliable readings.

Types of parameters and instruments that can be used to assist in the operation of an incinerator include the following:

1. Temperatures
   -Optical pyrometers for flame and wall temperatures in the range of 2,200 to 2,500F

-Shielded thermocouples (Chrome-Alumel) for furnace temperatures in the 1,400 to 1,800F range, and iron-constantan in duct temperatures down to 100F Gas- or liquid-filled bulb thermometers for duct temperatures below 1,000F and for ambient temperatures and water temperatures

2. Draft Pressures

   -Manometers and inclined water gauges for accurate readout close to the point of measurement

   -Diaphragm-actuated sensors where remote readouts are desired

3. Gas or Liquid Pressures from 1 to 100 psi

   -Bourdon-tube pressure gauges for direct readout

   -Diaphragm-actuated sensors for remote readout

4. Gas Flows

   -Orifice or venturi meters with differential pressures measured by draft gauges

   -Pitot tubes and draft gauges

5. Liquid Flows

   -Orifices with differential pressure measurement

   -Propeller-type dynamic flowmeters

   -Weirs

6. Electrical Characteristics

   -Voltmeters, ammeters, and wattmeters

7. Smoke Density

   -Photoelectric pickup of a light beam across the gas duct

8. Motion

-Tachometers for speeds of fan, stoker, or conveyor drives

-Counters for reciprocating stokers and conveyors

9. Visual Observation

-Vidicon closed-circuit television cameras for viewing furnace interiors, furnace loading operations, or stack effluents

-Peep holes in furnace doors

-Mirror systems

10. Weight

-Motor truck platform scales for measuring the quantity of incoming solid waste and outgoing residue, fly ash, and siftings

-Load cells for automatically weighing crane bucket contents

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IV. OPEN BURNING

A. DESCRIPTION OF SOURCE

Open-burning is the practice of burning waste materials on-site and out-of-doors in which the burning pile is directly exposed to the atmosphere. The waste materials are usually generated from a nearby process [illegible] activity, collected into piles and set on fire; or they may consist of natural vegetation such as weeds or agricultural, forestry or other natural products which are burned standing or are cut down and collected into piles and then burned. Whole structures such as automobile bodies and houses may also be set on fire either deliberately or accidentally. Burning in pits, in open containers such as oil drums or bins not designed as incinerators is another form of open burning. Food preparation in the out-of-doors, such as barbecueing, bonfires and open drum fires for heating purposes are sometimes defined as open burning practices, depending on local regulations.

Open burning is a virtually uncontrollable source of air pollution and should be prohibited. The type and amount of material being burned, the location of the burning, frequency of burning, the purpose of the burning, and the rates of contaminants emitted complicate any attempt to control this practice. Smoke, particulates and fly ash are the principal emissions as well as partial products of combustion such as carbon monoxide, oxides of nitrogen, hydrocarbons, aldehydes, and ketones. In addition, wastes containing ammonia, nitrogenous, sulfurous materials, animal matter or other material may produce odors.

B. TYPES OF OPEN BURNING

The handling of open-burning and control of emissions (where open burning is permitted) varies with the type of operation or activity with which the burning is connected. The following types of open burning may be noted:

1. Household Wastes

   These may consist principally of paper and wood products, particularly sulfide treated materials, and organic matter (fats oils, vegetable matter, plastics and a variety of other materials). Open burning of garbage, rubber products, green vegetation, plastics and other highly organic or carbonaceous materials should never be permitted.

   The burning of fallen leaves in the autumn in piles, in gutters, and containers with screened curtains is widely condoned although many communities are banning this practice. The collective contribution to community smoke levels by many householders burning leaves, particularly in the fall, can be substantial. Besides presenting an important air pollution problem, the smoke may contain allergenic materials, such as oils and pollens which may affect susceptible individuals with respiratory disorders. Any class of open burning which is dispersed among the general population should be eliminated.

   Open-burning by householders should be prohibited, particularly in large cities. Even in rural or semi-rural areas, open-burning by householders should be prohibited or regulated by fire department and air pollution control agencies.

2. Construction and Demolition Wastes

   These usually consist of waste wood materials, including bark, chips and saw dust. Wood that is kiln dried and uncontaminated, e.g., furniture manufacturing wastes can be stacked to provide "underfire" air and ignited to quickly produce a hot fire and comparatively little smoke, although organic pollutants such as pyroligneous acids, and aldehydes are emitted. Creosoted lumber, oily woods, oil rig timbers, rubber or plastic coated wires or other materials which produce dense black smoke should never be burned. Wood coated with oil and lead-based paints should not be burned or if burned, included in relatively small quantities with largely clean woods and cardboard. Contaminated non-combustible substances such as paint cans or oil drums should not be charged to the burning pile.

Where burning is permitted in construction and demolition activities, attempts should be made to segregate combustibles from noncombustibles, and highly carbonaceous and oil soaked, stained or coated wastes should be segregated from the clean wastes and hauled away. Wet material should be dried before burning or hauled to a dump or to an approved municipal incinerator.

Undesirable material, if permitted by local ordinances, should be carefully fed to an existing hot fire in small quantities. Refuse piles should be carefully stacked to "sandwich" wastes so that the material used to kindle the fire, such as paper and cardboard, is at the bottom of the fire, and the heavier materials are near the top. The material should be stacked to allow for circulation of air, but should not be too loosely packed as fly ash may result. Fires should be constantly attended. The operator should periodically stir the contents when smoke occurs or extinguish the fire if the smoke gets out of hand, or a dangerous situation occurs.

3. Salvaging Operations

These usually consist of the burning off of rubber, plastics, textiles, upholstery stuffings and other materials from junked or waste products to recover metals which have economic value. Major sources of this type of interest to the inspector are the preparation of motor vehicle hulks for the scrap market and salvaging of metal wires. These operations when burned in the open are a major source of large volumes of dense black smoke. Burning of this type should be one of the first forms of open burning to be prohibited. Where it is not, the operations should be cited under smoke and opacity violations. Reclamation activities of this type can be conducted in approved multiple-chamber incinerators (see Section II., Incinerators).

Automobile bodies can be manually stripped. Blow torches are frequently used to facilitate this operation. Automobile bodies are prone to catch on fire either deliberately or accidentally, with the latter frequently used as an excuse for the burning. Wrecking yards should be kept under frequent surveillance and normal practices observed, including the prevention and handling of runaway fires. Wrecking yards generally erect tall fences which interfere with the inspector's observation of the premises. The inspector should frequently enter the yard.

4. Open Dump Burning

Dump burning consists of the burning of large accumulations of mixed refuse which are transported to and deposited at the surface of the dump site. Although this practice continues in some communities, it is rapidly disappearing.

In view of the volume and range of materials burned, enormous quantities of smoke and other contaminants are emitted. Control is usually achieved by injunctive action, inter-agency cooperation, or by special legislation prohibiting the practice. However, elimination of the practice will require development of alternative means of final disposal such as sanitary land fill, in which the rubbish is compacted and buried, the use of specially designed municipal incinerators, removal of rubbish at sea, or use of rubbish in special land fill projects. Sanitary land fill operations, however, must be closely observed to prevent the admission and circulation of underground air which promote underground fires. Dump odors can also be released causing nuisances to neighborhoods situated nearby. The inspector should check the dump site to assure that no openings and fissures are permitted in the ground. Under proper conditions, spontaneous combuction and smouldering materials can occur for many days. These can be extinguished by recompacting the earth.

5. Agricultural Burning

Agricultural burning consists of burning of standing vegetation or crop stubble, cuttings, trimmings and prunings, dead fruit trees, dried grasses, swamp grasses, sugar cane, straw stacks, potatoe and peanut vines, citrus groves, cotton ginning burrs, and animal wastes, including manure piles.

The greatest amount of open-burning tends to be performed during and after the harvest season. Burning is also often performed during cleaning of agricultural lands for conversion to residential, commercial or other property.

Emissions include blue, brown or white smoke. The burning of forestry products etc., can result in black smoke. Forest fires due to slash burning or to accident will produce large quantities of soot and fly ash, in addition to smoke. Plumes from all burning can be voluminous and travel long distances.

Agricultural burning, when associated with the raising of crops and animals for human consumption, is often permitted, although the practice has been banned when alternative disposal methods are found. Agricultural wastes, including uprooted trees and tree stumps, can be cut up into small pieces and disposed of in cut and cover dumps. Forest scraps can be processed by chipping or crushing and can be used as raw materials for Kraft Pulp Mills or processes producing fibreboard, charcoal briquettes or synthetic firewood.

Agricultural waste material can be disposed of in approved stationary or mobile multiple-chamber incinerators, and air curtain destructors, although methods of disposal other than combustion--such as composting and cut-and-cover dumps--are preferred.

The burning of trees, brush and lumber wastes in land clearing operations can be effectively performed in an open pit with a portable Air Curtain Destructor or equivalent device.(1) The pit may be approximately 8' across, 15' wide and 12' deep, unlined or lined with refractory material (e.g., firebrick and reinforced concrete). The destructor consists of an air blower, driven by an industrial engine (approximately 50 h.p.), a plenum chamber and a nozzle. The blower delivers approximately 800 scfm of air for each foot of length of the pit, against a static pressure in the plenum of 10 inches of water. This arrangement provides an air velocity of 150' per second or about 100 mph in a flat sheet or curtain of air blowing diagonally downward across the pit. The air is deflected by the back wall to the bottom of the pit and is directed across the pit against the material to be destroyed, and finally upward at the front wall until it reaches the under side of the curtain. This sets up ideal conditions for combustion. The gases that finally escape through the air curtain have been stripped of any solid waste material that has not completely burned. The destructor can burn about 5 tons of trees and brush per hour, or about an acre of refuse material per day.

Agricultural burning, when permitted, can be confined to days on which air pollution potentials are minimal. Care should be taken not to burn materials that are wet or contaminated. Vegetation containing large amounts of pesticides or which include possibly poisonous or allergenic materials should not be disposed in a manner which exposes individuals to the emissions.

6. Coal Refuse Piles

Coal refuse from mine tailings should be kept under constant surveillance. These may consist of millions of tons of refuse which can ignite due to accident or deliberate action. Coal refuse piles should be allowed to cool before fresh waste material is added, or they should be repiled. The piles should also be compacted or sealed with impervious material, or injected with slurries of non-combustible material where holes or fissures appear. As in land fill dumps, compaction and sealing of the piles prevent air circulation and the chance of spontaneous combustion. Also such potential kindling materials as mine timbers, paper, vegetation and other combustibles should be segregated and disposed of separately. (See Coal Preparation Plants, Chapter 7, Section XIII and Mining, Chapter 7, Section XII.)

7. Other Sources

Open-burning from industrial and commercial sources can consist of materials which are involved in activities conducted at the source. The burning of industrial wastes is likely to result in undesirable emissions particularly where chemicals, packing materials, or oily or carbonaceous materials are involved. The actual or potential practice of open-burning at industrial sites should be looked upon as a possible operation in the overall industrial activity and should be reported by the inspector. Since private disposal facilities and approved multiple chamber incinerators are usually available to industry, the practice should be prohibited.

C. CONTROL OF OPEN BURNING

The extent of open-burning conducted is largely a function of the type, quality and coverage of the waste-pickup and disposal practices of the community. Factors that may affect the extent of open-burning conducted include:

1. Type of refuse pick-up service available to householders, and commercial and industrial institutions.
2. Provision for separate or combined refuse collection for different materials.
3. Provision for recovering or recycling of salvageable materials.
4. Waste storage and materials handling practices at the source.
5. Collection method, frequency and schedule.
6. Transport routes and transfer points.
7. Availability and location of disposal sites and capacities.
8. Attitude of public towards both waste disposal and air pollution.
9. Availability of other waste disposal methods, e.g., incineration.
10. Extent of public and private services available, fees and other assessments.
11. Method of final disposal: incineration, sanitary land fill, open dumping, composting, other.

The extent or coverage, access to facilities, and costs to users are some of the principal factors which determine the types of open-burning prohibitions and regulations that can be applied. Where pickup services and disposal facilities are inadequate or incomplete, open-burning is permitted under controlled conditions in some communities.

Where service is adequate and comprehensive, almost all forms of open-burning can be prohibited. In between these two situations, a combination of disposal service, open-burning regulation, and specific prohibitions may be applied, until such time as it is feasible to ban the practice all together. The types of regulations that can be applied include:

1. Restriction on excessive emissions by use of Ringelmann and opacity regulations.
2. Prohibition of open burning.
3. Specification of approved method of incineration.
4. Limitation on substances that can be burned, e.g., garbage and smoky material such as rubber products, wet materials and hazardous substances.
5. Restriction of burning to prescribed burning hours.
6. Restriction of burning to certain locations.
7. Restriction of burning days according to official air pollution forecasts.
8. Application of public nuisance, where complaints have been made.

9. Requirement of burning permit by fire department and/or air pollution control or other agency.
10. Fire tending requirements, including minimum distance to habitable structures.
11. Use of tree and brush shredders; mobile multiple-chamber incinerators or air curtain destructors; use of oil or gas fired salamanders to replace burning in drums for the purpose of outdoor heating.

While most open-burning can be prohibited, some burning may still be permitted for health, safety, and conservation reasons either by official agencies or under their control. Examples are prevention of a fire hazard by burning off dry weeds and vegetation, slash burning, and emergency measures required to dispose of contaminated materials to prevent the spread of possible disease.

Control programs should proceed in a direction which leads to eventual elimination of open-burning altogether. This must be accomplished by institution, expansion and coordination of pickup services, recycling of waste materials, sanitary land fills, composting, waste heat incineration, and rail or boat hauling (where necessary). Often such programs must be accompanied by an intensive local public education program that will result in an awareness of the waste disposal problem and support for improved disposal methods. The inspector can play an important role in informing the public.

D. INSPECTION POINTS

Open-burning differs from other stationary source problems in that it is not conducted at a fixed location, nor are the persons responsible for setting fires always easily located. Fires may be set and abandoned, and the individuals responsible may have to be determined from the business licensing division, the owners of the land, or from others residing or working nearby.

The inspector should note the following in his reports or violation notices:

1. Size, diameter and height of fire.
2. Location--distance from any near structure, corner of lot and other reference point.
3. Materials being burned; describe whether green or wet.
4. Possession of permit by operators from local fire department or other agency; expiration date, conditions.
5. Is fire being conducted on a day when high air pollution conditions have been forecasted?
6. Means available to extinguish the fire.
7. Individuals in attendance at the fire. Was the individual adding material to the fire, stirring the fire, raking or controlling the fire in any manner?
8. Name of individual in attendance, name of firm, organization or individual he works for or represents.
9. Attempts being made to extinguish the fire on arrival, during visit of inspector, or later.
10. Did the operator attempt to segregate heavy material, contaminated material, heavies or other material which is capable of emitting heavy quantities of smoke?
11. Was the fire in view at the time of the observation. Position of Inspector relative to reading of emissions.
12. Record of Ringelmann and opacity on smoke observation sheet. Show continuous time interval for each opacity and density, color change and total violation time in minutes.
13. Comments of operator and/or owner.

14. Weather conditions during observations including wind direction.
15. Status of plume at end of recorded observation.
16. Source of the materials.
17. Reason for the fire.
18. How often fires are set.
19. Availability of pick-up services in the area.

REFERENCE

1. Geyer, O. W., and E. A. Rudulph. Minimizing Air Pollution from Open Burning with an Air Curtain Destructor. Air Pollution Control Association, paper 70-143.

V. ODOR DETECTION AND EVALUATION

A. INTRODUCTION

All air pollutant emissions of concern from the standpoint of field operations divide into those which are perceptible to the human observer (e.g., enforcement officers, complainants), and those which are imperceptible. Imperceptible contaminants cannot be consciously perceived through the senses (seeing, hearing, smelling, feeling, touching) at normal ambient concentrations and can include such contaminants as carbon monoxide, hydrocarbons, and oxides of nitrogen. They are primarily detected and measured through ambient air sampling and source sampling and analysis, or are indirectly inferred through the determination of design, operational and process parameters associated with equipment and systems capable of emitting air contaminants. These factors are dealt with principally in Chapters 6 and 7 of this manual.

The perceptible emissions are those, like dust, smoke, and fumes, which can be seen, or leaking gases which can be heard, or gases and vapors which can be detected through the sense of smell. The field enforcement officer's stock-in trade are these forms of emissions. Indeed, he should be trained to be an expert in detecting, describing, quantifying these emissions and in establishing their sources and causes.

The field enforcement officer will be concerned with odors from a number of standpoints:

1. To identify odors that are the cause of a public nuisance and to establish the extent and frequency of the public nuisance.

2. To identify the contaminants (the odorants) and sources responsible for odors and to collect evidence to establish the extent and cause of the public nuisance or violations of emission regulations.

3. To assess odors as a means of identifying emissions in general and of evaluating the effectiveness of air pollution control practices.

The problem in the evaluation of odors is essentially that there are no reliable objective methods for field identification of specific compounds and conditions causing the odors, or for quantifying the concentration of odorants in the ambient environment. These aspects of odor evaluation must be treated as scientific investigations. Nevertheless, a trained enforcement officer should be sufficiently expert in odor evaluation so that:

1. He can objectively evaluate the perception and his own level of odor sensitivity in relation to complainants and the general population.

2. He has thorough knowledge of the sources which produce odors and the physical conditions that affect odor potentials.

3. He can identify odors in the field.

4. He has knowledge of the conditions which affect odor perception and of scientific techniques used in odor evaluation.

Thus, to be an expert, the enforcement officer should have knowledge of both the perceptual and the scientific aspects of odor investigation. These are treated in this section.

B. CHARACTERISTICS OF ODORS AND ODORANTS

A major difficulty in dealing with odors as an air pollution problem arises from the fact that an odor is not an air contaminant but is a property of air contaminants which can only be detected or measured through its effects on the human organism. Briefly, an odor is that property of a substance which affects the sense of smell. A contaminant which has an odor is called an odorant.

The capacity in humans to perceive odors varies considerably among individuals, and in one individual from time to time. Some persons ("anosmiacs") are very insensitive to odors, while others may be acutely sensitive to odors unnoticed by most people. This variability of individual sensitivity complicates the problem of estimating the prevalence of an odor nuisance.

The air pollution inspector is primarily interested in establishing the existence of an odor problem according to legal criteria: i.e., a problem which constitutes a nuisance to a considerable number of persons over a continuing or significant period of time. Both of these elements are important from a practical standpoint, since there is little value in devoting substantial effort to the solution of a nonrecurrent problem or one not affecting an appreciable number of persons in the community.

In such problems, the inspector is concerned with (1) identifying the odor, (2) rating the odor's intensity, (3) identifying the odorant, (4) establishing the frequency of the nuisance, (5) locating the "odor route," (6) locating the source of the odorant, and (7) influencing some operational or engineering control over the odorant.

1. Odor Perception

There are a few characteristics about odor perception which the enforcement officer should be familiar with in estimating whether an odor problem exists. These are as follows:

a. The olfactory sense becomes fatigued after continuous perception of an odor.

b. An odor is usually detected whenever there has been a significant change in odor quality or intensity. A pleasant odor can become objectionable to one who has become used to it under continuous exposure, when it increases in intensity.

c. Odors do not, in themselves, cause physical disease. The odor of many toxic materials (e.g., chlorine, sulfur dioxide, hydrogen sulfide) may serve as a warning agent, however. Odors, also, may bring on nausea and have an adverse effect on asthmatics.

d. A person's ability to perceive odors varies from day to day.

e. Compounds of different constitution may yield similar odors, whereas compounds of very similar constitution may yield different odors.

f. An unfamiliar odor is more likely to cause complaints than a familiar one.

g. The perception level of odors decreases with increasing humidity. High humidity tends, however, to concentrate odors in a given locality.

h. Odor quality may change upon dilution.

i. Some persons can detect certain odor qualities but not others.

2. Odorants

It is not necessary for enforcement purposes to consider all of the odorants. Nearly all substances known, excepting those to which one is accustomed such as oxygen, have an odor. According to Moncrieff,(1) potent odorants generally possess a significant degree of volatility and chemical reactivity such as are exhibited by the aldehydes and various classes of hydrocarbons. Also, materials of high vapor pressure tend to yield odors more readily than those of low vapor pressure.

The average person would find all familiar environmental odors objectionable were they strong enough. There is no problem about identifying these through mental association. Such familiar odors as coffee, gasoline, moth balls, roses, tobacco, wood smoke, jasmine, paint, skunk do not need further definition to most people and can be termed characteristic odors.

However, there are many odors whose qualities are familiar though the odorants themselves are not. These are the so-called chemical odors, as complainants might call them, associated with chemical and petrochemical processes. The odors of skunk, garlic, onions and cabbage, for example, may arise from various sulfur compounds (ethyl, methyl, propyl and butyl mercaptans, respectively) generated from oil-refining processes. These are good examples of the fact that compounds of similar constitution have different odors.

We may further distinguish between strong, pungent "chemical" odors, which offend primarily because of intensity, and those which are obnoxious or malodorous because of their quality. The latter are odors originating from the handling and processing of organic compounds containing nitrogen and sulfur. The odors arising from nitrogenous compounds may be associated with animal odors and decomposition and putrefraction of animal tissue. The odors arising from sulfur are characterized by "rotten egg," "skunk," and "decayed cabbage." They also include the acrid, bitter sulfide odors found in metallurgical operations.

3. Odor Parameters

In investigating odor complaints to establish the existence of a nuisance, the enforcement officer should attempt to identify the odorant, describe the odor and establish its objectionability, and provide some indication as to its severity. Nader(2) in describing perceptual measurements of odors in the laboratory, defines the following set of parameters pertinent to such an evaluation.

- Quality
- Intensity
- Acceptability
- Pervasiveness

Although developed primarily for experimental use, these parameters are also useful for characterizing odors in the field. Skill in evaluating odors lies in the ability to distinguish the separate characteristics of the odor, and in isolating the smell from other senses (taste, feel, sight and hearing). Normally sensitive persons can develop such skill through training.

a. Quality

The quality of an odor may be described either in terms of association with a familiar odorant, such as coffee, onions, etc. (characteristic odors) or by associating a familiar odor with an unfamiliar odorant. Aside from such direct descriptive terms, the observer, in an attempt to be complete and accurate, may add modifiers to his description to indicate shades or overtones of an odor. These may actually include subjective reactions such as "fragrant," "foul" and "nauseating," or characteristics of odor which may be associated with the sense of taste such as "bitter," "sweet," "sour," "burnt," or even partially with the sense of touch as far as contaminants which are irritating are concerned, such as "pungent," "acrid," "acidic," and "stinging." As a matter of fact, a contaminant may sometimes affect more than one sense. An irritant can be smelled, cause eye-irritation and be tasted.

Odor terminology is meaningless without actual exposure through odor training. Therefore, the inspector should be exposed to samples of typical odorants found in the local industry, so that he can be prepared to make quick and accurate identifications. There is no substitute for this kind of training. Verbal descriptions of odors do not implant as vivid an imagery in the mind as do descriptions of visual or auditory phenomena.

A few of the well-known odor classification systems are indicated here. They are useful in training inspectors in making associations and analyzing the various component sensations which odors may produce. For field purposes, one system is as good as another. The advantage of all systems is that they yield a usable odor vocabulary, as shown in Figure 6.5.1 and below.

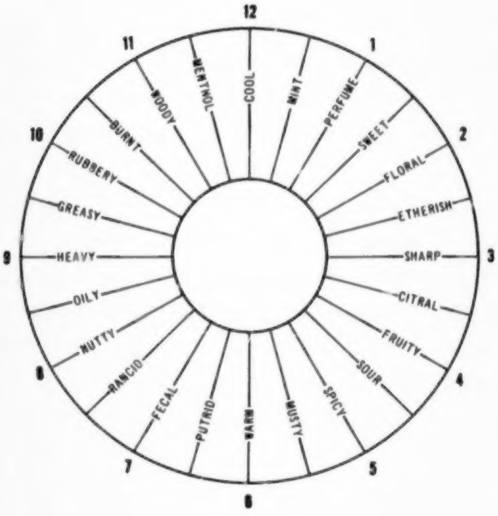

12
COOL
MINT
1
PERFUME
SWEET
2
FLORAL
ETHERISH
3
SHARP
CITRAL
FRUITY
4
SOUR
SPICY
5
MUSTY
WARM
6
PUTRID
FECAL
7
RANCID
NUTTY
8
OILY
HEAVY
9
GREASY
RUBBERY
10
BURNT
WOODY
11
MENTHOL

Figure 6.5.1. ODOR CHART. This chart attempts to present a complete range of odor terms which can be used to construct phrases of odor description. Each of these terms, moreover, can be numerically fixed from a "clock" chart for map notations, tabulations, or general reporting. Reported by Gruber, and attributed to Dean Foster, Head of the Psychophysical Laboratory at the Joseph E. Seagram Co., Louisville, Kentucky. (SOURCE: Weisburd, Reference 14.)

Henning's Odor Classification(3,4)

Based on Six Types of Odor Classification

1.	Spicy:	Conspicuous in cloves, cinnamon, nutmeg, etc.
2.	Flowery:	Conspicuous in heliotrope, jasmine, etc.
3.	Fruity:	Conspicuous in apple, orange oil, vinegar, etc.
4.	Resinous:	Conspicuous in coniferous oils and turpentine.
5.	Foul:	Conspicuous in hydrogen sulfide and products of decay.
6.	Burnt:	Conspicuous in tarry and scorched substances.

Crocker-Henderson Classification(3,4)

A Condensation of the Henning Arrangement

1. Fragrant or sweet.
2. Acid or sour.
3. Burnt or empyreumatic.
4. Caprylic, goaty, or oenanthic.

b. Intensity

Intensity is described by some numerical or verbal indication of the strength of an odor. Various intensity scales have been devised. The average observer or complainant can be expected to distinguish three levels of intensity, characterized as weak, medium and strong. A useful rating system especially adapted for field work is as follows:

Rating	Description
0	No detectable odor.
1	Odor barely detectable.
2	Odor distinct and definite, any unpleasant characteristics recognizable.
3	Odor strong enough to cause attempts at avoidance.
4	Odor overpowering, intolerable for any appreciable time.

This system depends on observation or reporting of behavior more than on subjective impressions of the complainant. The fact that a person desperately attempts to avoid a strong and unpleasant odor is clear and verifiable indication of its intensity. Reports of odor intensities of 2 or higher on this scale may be particularly relevant in establishing the existence of a legal nuisance.

For scientific purposes, on the other hand, an odor rating which does not depend so heavily on the objectionable character of an odor is usually preferable. Such a system, long used by expert evaluators, is the following:

Intensity	Expert Description
0	No odor
1	Very faint
2	Faint
3	Easily noticeable
4	Strong
5	Very strong

This system has the advantage of distinguishing the intensity parameter from the acceptability parameter in a more definite manner.

c. Acceptability

An odor may be either acceptable or unacceptable depending on its intensity and quality. Thus odors normally considered as pleasant, such as flower fragrances and perfumes, may become unacceptable only at very high concentrations (i.e., at very high intensities on the scientific scale) whereas obnoxious odors may be unacceptable at much lower concentrations, where they are not clearly recognizable.

d. Pervasiveness

The parameter of pervasiveness refers to the tendency of an odor to resist being dissipated by dilution of the air in which it occurs. Pervasiveness in this sense is related to the nature of odorant and is not readily determined except by experiment. Nevertheless, a highly pervasive odor is one which, in the field, will tend to be detectable in sheltered areas over a longer period of time, and will therefore in some incidents be easier to track than a less pervasive one.

C. DETERMINANTS OF ODOR PERCEPTION

Odor is a property of an odorant, but the report of a perceived odor is mediated by the nervous system and the brain of an observer. Therefore differences in reports of odor perceptions may be due partly to differences in the physical conditions of exposure, and partly to differences in the physiological and psychological status of the observer. In view of these considerations, the main parameters determining an odor report may be listed as

- Identity of odorant (or odorants)
- Concentration(s) of odorant(s).
- Ambient conditions.
- Status of observer.

The relevance of these parameters to problems of odor evaluation is discussed in the following subsections.

1. Identity of Odorant

The chemical identity of the substance responsible for an odor is usually the main determinant of the quality of the odor, as discussed above. Thus, in principle, it should be possible to infer the identity of the odorant from the perception of odor quality. To a certain extent this is feasible and is done. An expert observer, trained to recognize the odors of various odorants at various intensities, is an invaluable asset in odor evaluation techniques.

The field enforcement officer should be trained to identify the odorants most often responsible for complaints within his area. So trained, he can often identify the cause of an odor problem by his own investigation in the field, even when the complainants are uncertain as to the nature or origin of the odor.

One difficulty that arises in the endeavor to associate particular odorants with their odors is that the chemical identities of odorous industrial air contaminants are not always known. Further, in some cases the odors are caused by mixtures of odorants which may vary in their proportions under different conditions of production; these variations can lead to changes in perceived odor quality, but usually within some limited range which does not prevent recognition by a trained observer.

Another complication in the recognition problem arises from the fact that odor quality may change with dilution. In mixtures of odorants this may be due to a difference in pervasiveness of the individual compounds; however, single odorants sometimes behave similarly.

Even when the chemical identity of the odorant or odorants is not known, it is often possible to attribute the problem to a particular source on the basis of recognition of an odor quality which is characteristic of that source. For example, Kraft pulp mill odors are commonly characterized as similar to rotten cabbage. It is known that such emissions contain several odorant compounds having recognizably different odor quality and pervasiveness; yet, practically anyone in a pulp mill community will identify the source from the "rotten cabbage" description.

2. Concentration of Odorant

The concentration of the odorant in the ambient air is the main parameter determining the intensity of the perceived odor, although ambient conditions and observer status may cause appreciable variations in perceived intensity. Other parameters being constant, the relation of odor intensity to odorant concentration is given by the Weber-Fechner law, which asserts that the intensity is proportional to the logarithm of the concentration. Pervasiveness is inversely related to the constant of proportionality (k) in the Weber-Fechner equation,

$$I = k \log(C/C_t)$$

(The larger $\underline{k}$ is, the more rapidly the intensity decreases as the concentration is reduced, and therefore the less pervasive the odor is.)

The Weber-Fechner law applies only for individual odorants, and only in the concentration range equal to or greater than the threshold concentration ($C \geq C_t$). For consistency with the Weber-Fechner equation, the threshold concentration should be defined as the maximum concentration of odorant which fails to yield a detectable odor. However, in practice it is usually defined as the minimum concentration (detection threshold) that produces a detectable odor, as this quantity is easier to determine and can differ from the other only slightly. Threshold concentrations of a given odorant as determined for different individuals show large variations corresponding to differences in individual sensitivities; therefore tabulations usually show values determined on a statistical basis, such as the average for several members of a panel.

In the case of perceived odors caused by mixed odorants, such as those from pulp mills, there are no generally accepted rules which can be used to relate odor intensity to the concentrations of the individual odorants. Studies(5) have shown that perceived odor intensities due to mixed odorants are often not those which would result from simple addition of the effects of the separated odorants. With some pairs the intensities are approximately additive, but in others they may be classified as

- Counteractive, in which the observed intensity is less than expected for one of the odorants alone;
- Suppressive, in which the observed intensity is less than expected for an additive effect, but greater than for a counteractive effect;
- Synergistic, in which the observed intensity is greater than that expected for an additive effect.

The determination of which of these categories applies to a given pair of odorants can only be made by experiment. Few such experiments have been carried out; therefore, it is not generally possible to predict the intensity relations of mixtures from a knowledge of the properties of the individual odorants.

3. Ambient Conditions

It is recognized that the evaluation of quality and intensity of an odor may be affected by the temperature and humidity of the air presented for evaluation. Unfortunately, there has been no study of the importance of these factors, and there is no known way of accounting for any such effects. In evaluations under laboratory conditions it is desirable to maintain such conditions reasonably constant, and at levels near average ambient air levels, during any series of tests designed to yield comparable results.

4. Status of Observer

The principal parameters of observer status which are relevant to odor evaluation may be listed as sensitivity, expertise, and physiological and psychological conditioning.

a. Sensitivity

The sensitivity of observers for any given odor varies widely, and the relative sensitivities of two observers vary inconsistently for different odors. Furthermore, independent observers often disagree substantially regarding odor quality, particularly when evaluating odors of mixed odorants. For these reasons statistical evaluations using panels of observers are more likely to provide reliable results than evaluations by individual observers.(6)

b. Expertise and Training

As discussed above, expertise can be developed to a considerable extent by study and training,(7,8) although it is necessarily limited by the physiological sensitivity of the would-be expert. With respect to quality, expertise consists in the ability to recognize and discriminate between a number of odorants, either singly or in mixtures. Relative to intensity, expertise permits reliable discrimination between a large number of graded levels of intensity. Thus, a trained person can detect a smaller percentage difference in concentration levels of a given odorant than an untrained individual. A recent study led to the estimate that, at least for some odorants, there appear to be 25 or 30 just-noticeable-differences over the range of perceptible intensities (from threshold to the maximum distinguishable), and that each j.n.d. corresponds to about a 60 percent increase in odorant concentration.

c. Physiological and Psychological Condition

A problem of physiological origin, in the evaluation or tracking of odors, is fatigue of the olfactory nerves, which tends to diminish the sensitivity of the evaluator. The effect is especially noticeable after prolonged exposure to a rather high intensity of odor, and may seriously complicate the conduct and interpretation of odorant threshold determinations in the laboratory.

Colds and other infections of the nasopharyngal tract can cause serious, if temporary, interference with the sense of smell and result in loss of sensitivity to many odorants. For observers in an odor panel, a preparation of a standard odor can be useful in checking on these variations in sensitivity from day to day; at least when the condition is not too obvious to need confirmation.

D. MEASUREMENT OF ODOR INTENSITY OR ODORANT CONCENTRATION

In odor incident investigations, it is desirable wherever possible to establish some quantitative estimate of the degree of odor involved, and of the relation between concentrations of odorant in the field and quantities emitted at the source. In cases where a single odorant with known characteristics is involved, this may sometimes be done by chemical or physical methods of analysis, with comparisons based on weight of odorant in various samples. However, for the rather more common case where the identity of the odorant is not established, or where mixed odorants are involved, the odor potential may be determined in terms of "odor units."

An odor unit is defined as the quantity of any odorant (or mixture of odorants) which, when dispersed in unit volume of odor-free air, produces a threshold intensity response. If a sample of a gaseous emission contains (say) 10 odor units per cubic foot, it can be inferred that when the sample is diluted with nine parts of odor-free air, the resultant mixture will have a barely detectable odor. Thus the "odor concentration" in odor units per cubic foot also describes the dilution factor required to reduce the odor to a just perceptible level. Although not directly expressible in terms of contaminant weight per unit volume, the odor concentration is analogous to other emission concentrations, for engineering purposes.

Odors both in ambient air and in odorous effluent streams should be evaluated by the inspector to confirm a pattern indicated by complaints. A quantitative basis may be established by the use of a portable dilution device, or samples of the air may be collected for later evaluation in the laboratory to confirm the inspector's sensory evaluation. Appropriate methods and devices for these purposes are discussed below.

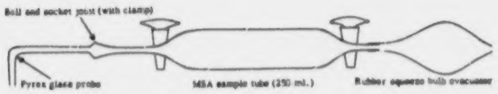
1. Sampling for Later Evaluation

To confirm field estimates of odor intensity, or to determine odor removal efficiency of control equipment, the investigator may collect samples of odorous gases of low moisture content by means of a glass probe connected by a ball and socket joint with clamp to a gas collection tube (e.g., a 250 ml. MSA sample tube) as shown in Figure 6.5.2. The odorous gas is drawn into the tube by a rubber squeeze bulb evacuator. (Rubber or plastic tubing or other absorptive or heat sensitive materials on the probe side of the sample tube should not be used.)

For gases with high moisture content, such as may be found in steam plumes, precautions are required to prevent condensation of water vapor and possible absorption of odorants in the liquid. This can be achieved by using a syringe and hypodermic needle to aspirate a smaller sample into the sample tube, previously filled with odor-free air. A system of this sort is also illustrated in Figure 6.5.2. (A capillary probe may be used, to minimize error due to dead space in the probe.)

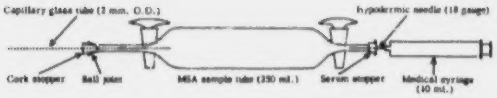
Sampling problems that must be dealt with include: (1) if sample is warm, condensation and cooling may result in the selective removal of odorants from the vapor phase; (2) odorous material may be sorbed on the walls of containers and on particulates in sample; (3) chemical changes after sampling may alter the odorant, etc.

A test kit convenient for field use(10) consists of six 250 ml. sample tubes, a hand aspirator, and several probes of glass tubing with ball joints for attachment to the sample tubes. A special capillary probe and syringe with hypodermic needle, for sampling gases of high moisture content, may also be included.



METHOD A

Ball and socket joint (with clamp)
Pyrex glass probe
MSA sample tube (250 ml.)
Rubber squeeze bulb evacuator



METHOD B

Capillary glass tube (2 mm. O.D.)
Hypodermic needle (18 gauge)
Cork stopper
Ball joint
MSA sample tube (250 ml.)
Serum stopper
Medical syringe (10 ml.)

Figure 6.5.2. SCHEMATIC DIAGRAMS OF ODOR SAMPLING APPARATUS. Method "A" is used to collect samples low in moisture content; Method "B," samples high in moisture content. The latter method permits primary dilution of odor sample in the field, and minimizes condensation of vapors on the inner surface of the sample tube.
(SOURCE: Weisburd, Reference 14.)

2. Dilution Techniques

Dilution techniques are applicable both to the inspector in his field observations and to the laboratory investigating team in providing for evaluation by odor panels.

For field use, either in odor patrol or in investigation of an odor incident, ambient air may be tested with the aid of a portable dilution device such as the "scentometer"(11) (Figure 6.5.3). This device is actuated by inhalation by the operator, thus dispensing with pumps and electrical power sources; holes which can be opened or closed by the fingers permit precalibrated dilutions of the ambient air stream with air which is simultaneously deodorized by an activated charcoal filter. A useful feature is that the observer can combat the effects of olfactory fatigue by breathing only deodorized air for a period prior to an actual test.

Various devices, mainly constructed on similar principles, have been used for dilution of odorants for laboratory evaluation. However, the method of choice both for simplicity and accuracy appears to be the syringe technique.(10) The odorous gas is displaced from the sample tube (for example, by mercury displacement) into a large graduated syringe, in which it is diluted by addition of odor-free air. Further dilutions are easily managed by the use of additional syringes, as illustrated in Figure 6.5.4. The last dilution, usually 10 to 1, is performed by the panelist, who is furnished with 10 ml. of sample injected into his 100 ml. syringe; he dilutes the sample to 100 ml. with ambient air before sniffing it, and records a positive or negative result as to detection of the odor.

For confirming the identity of suspected odorants, or for quantitative determination of concentrations of identified odorants, gas chromatography can be performed, using samples no larger than those necessary for the organoleptic evaluation of odor.

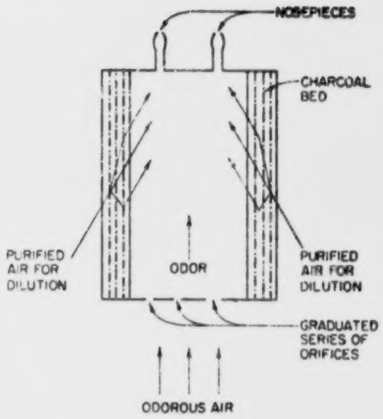

NOSEPIECES
CHARCOAL BED
PURIFIED AIR FOR DILUTION
ODOR
PURIFIED AIR FOR DILUTION
GRADUATED SERIES OF ORIFICES
ODOROUS AIR

Figure 6.5.3. SCHEMATIC OF SCENTOMETER. Odorous air passes through graduated orifices and is mixed with air from the same source, which is purified by passing through charcoal beds. Dilution rates are fixed by the orifice selection. (SOURCE: Gruber, Reference 11.)

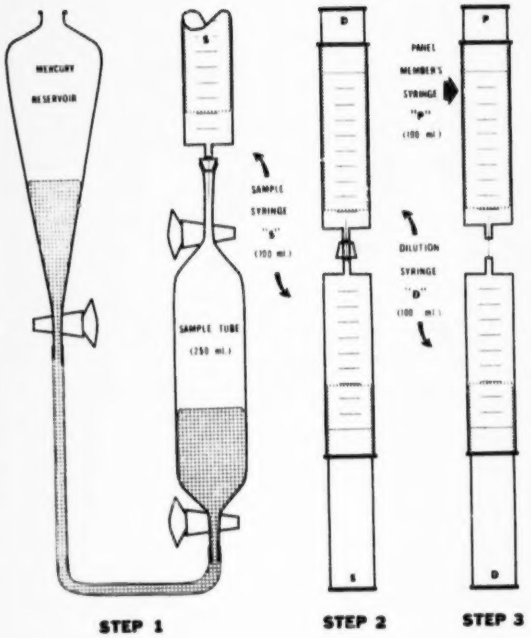

MERCURY
RESERVOIR
S
SAMPLE
SYRINGE
"S"
(100 ml.)
SAMPLE TUBE
(250 ml.)
D
S
PANEL
MEMBER'S
SYRINGE
"P"
(100 ml.)
DILUTION
SYRINGE
"D"
(100 ml.)
P
D
STEP 1
STEP 2
STEP 3

Figure 6.5.4. EQUIPMENT USED FOR TRANSFERRING AND DILUTING ODOR SAMPLES (SOURCE: Air Pollution Engineering Manual, Reference 15.)

E. DETERMINING SOURCES RESPONSIBLE FOR ODORS

1. Odor Patrol

The possibilities of instituting quick, effective action to control odors when complaints arise depend, to a large extent, on the field officer's intimate knowledge of the odor potentials of the various industrial and other sources within the community. It is therefore necessary for him to become familiar with likely source activities.

A simple odor patrol is probably the best indicator of existing or potential nuisance from odorous discharges. This consists of a regular periodic patrol around selected plants or in selected areas, documented by notes as to observed odors, with time, location, and wind direction. Special patrols for complex industries such as refineries and chemical plants may be assigned to personnel specially trained for them, and cognizant of the particular activities which entail an odor potential. A record of such odor patrols is also useful in indicating where odor control efforts are most required.

Fortunately, there is a substantial background of odor control experience to indicate what types of activities are likely causes of obnoxious odors. Where particular processes have not been subject to odor control, odor problems are likely to arise from the following industries or industrial activities:

a. Petroleum Industry

b. Petrochemical Plant Complexes

c. Chemical Industries

d. Pulp and Paper Mills

e. Coke Ovens and Coal Processing

f. Metallurgical Industries and Foundries

g. Coffee Roasting and Other Food Processing Industries

h. Meat Processing and Animal Industries, including
    (1) Feedlots

    (2) Livestock Slaughtering

    (3) Inedible Rendering

    (4) Fish Canning and Processing

    (5) Meat Packing

    (6) Poultry Ranches and Processing

    (7) Tanneries

i. Paint and Varnish Manufacture and Coating

j. Sewage Treatment Plants

k. Tar Coating Operations

l. Combustion Processes, including
    (1) Gasoline and Diesel Engine Exhaust

    (2) Maladjusted Heating Systems

    (3) Incinerators

Further details regarding these industrial processes and their potential for generating odors are presented in this and other chapters of this manual. (See, in particular, Table 5.1 Chapter 5, Chapter 7: Kraft Pulp Mills, Rendering Plants, Petroleum Industry, Aluminum Reduction Plants, Fertilizer Plants and Roofing Plants.) Field officers should become familiar with the details of all such operations in the area.

Of course, similar activities under nonindustrial auspices may also cause odor problems. Not uncommon are odorous emissions from domestic and municipal incinerators, burning dumps, trash fires, agricultural burning, sewage plants, and diesel engine emissions.

2. Field Investigations of Odor Incidents

In a routine inspection of an industrial plant, the normal air pollution configuration is tracked from cause to effect--from the feed input of equipment to the effects of the contaminant generated from the equipment on receptors and the environment (see Chapter 4, Section II). The tracing of an odor problem reported as a public nuisance is just the reverse of this procedure. The investigation begins with the complainant and his environment and works back to the equipment responsible in the following steps:

- Interview of complainants to obtain as much factual information as to the intensity, evidence and source of the contaminant.
- Identification of the contaminant causing the nuisance.
- Tracking the contaminant to its source or sources.
- Inspection of the equipment at the source to determine plant's capacity to emit the contaminant.
- Collecting signed district attorney affidavits or other official forms from complainants who desire to testify in court.
- Serving notices of violation to the source or motivating plant management to remedy the situation.

Most of these techniques are described in Chapters 2 and 4 of this manual. This chapter is primarily concerned with the problem of tracking and identifying sources of odors, assuming that the source is not immediately determined.

In an odor nuisance, the field officer must establish the existence of two areas: the effect area, that is, the area over which the nuisance effect exists; and the source area--that area which can be assumed by logical tracking techniques to contain the specific source or sources of the nuisance contaminant. The determination of a source area is often a first step in isolating the exact source and cause of the nuisance, especially in those cases where the specific source is difficult to establish initially.

a. Determining Air Flow from Source

The basic problem in an odor nuisance is to establish the flow of air masses from a source of air pollution to establish responsibility, or to determine relative contributions to the problem from two or more sources. This procedure is otherwise known as source tracking, and is especially applied when the source of the nuisance is originally unknown. This basically involves determination of wind direction and velocity for the purpose of triangulating the source.

In source triangulation, only two vectors are required, i.e., wind directions taken on separate occasions and locations at times of nuisance occurrence. Wind direction is always ascertained from the direction in which it is blowing. (A south wind blows from the south.) Wind direction can be determined from flags, steam or smoke plumes, finger-wetting, or other indicators.

The interview with the complainant should also attempt to establish the wind direction at the time of contamination. The investigator should instruct complainants and/or observers in recurring problems to maintain a record of time, intensity and wind direction. If this is not possible, the investigator should attempt to estimate the time the contamination is likely to occur, so that he can logically schedule reinspections.

In complex cases involving heavily industrialized communities with many possible sources, or where contamination or nuisance does not appear to be localized according to wind direction, the inspector may plot a wind rose, based on local meteorological data. A check with the enforcement agency may disclose prevailing wind patterns and other pertinent micrometeorological data for the area in question.

A conclusive determination of air flow movement may be made by tracer studies utilizing tracer materials and aerosol filter sampling devices. Tracer material may consist of fluorescent dusts, spores, lycopodium powder, radio-active materials, neutron activation powders, zinc cadmium sulfide or zinc silicate, or other material which can be recognized and counted under a microscope and which range in size from 1.5 to 2 microns in diameter. Tracer materials can be either introduced into a system at the source of air pollution or blown by portable blower equipment into the atmosphere near the suspected source. Enforcement officers may be deployed according to wind flow for sampling in or near the receptor and suspected source areas. The greater the distance to the suspected source area, the greater the number of detection stations required. The sampling is also performed either under atmospheric conditions which occur during the nuisance or during periods of atmospheric stability.

In complex cases, the following tracking results are recorded on a map as shown in Figure 6.5.5:

- Location of complainants and distances from possible sources
- Plant source layout showing principal types of equipment which may be involved.
- The number of complaints, and frequency of complaints as well as the time of day.
- Observations by inspectors at various points to fill in any gaps in data.
- The tracked contaminant routes and vectors of triangulation.
- Wind roses or other indications of wind direction.

b. Tracking Odors

During the inventory inspection conducted at all of the industrial plants, investigators attempt to initiate correction on all odor potential processes in order to prevent nuisances. It should be kept in mind, however, that if a plant is otherwise in compliance, but produces odors, no nuisance is involved if no one is affected. Nevertheless, in such cases, the investigator describes the odor

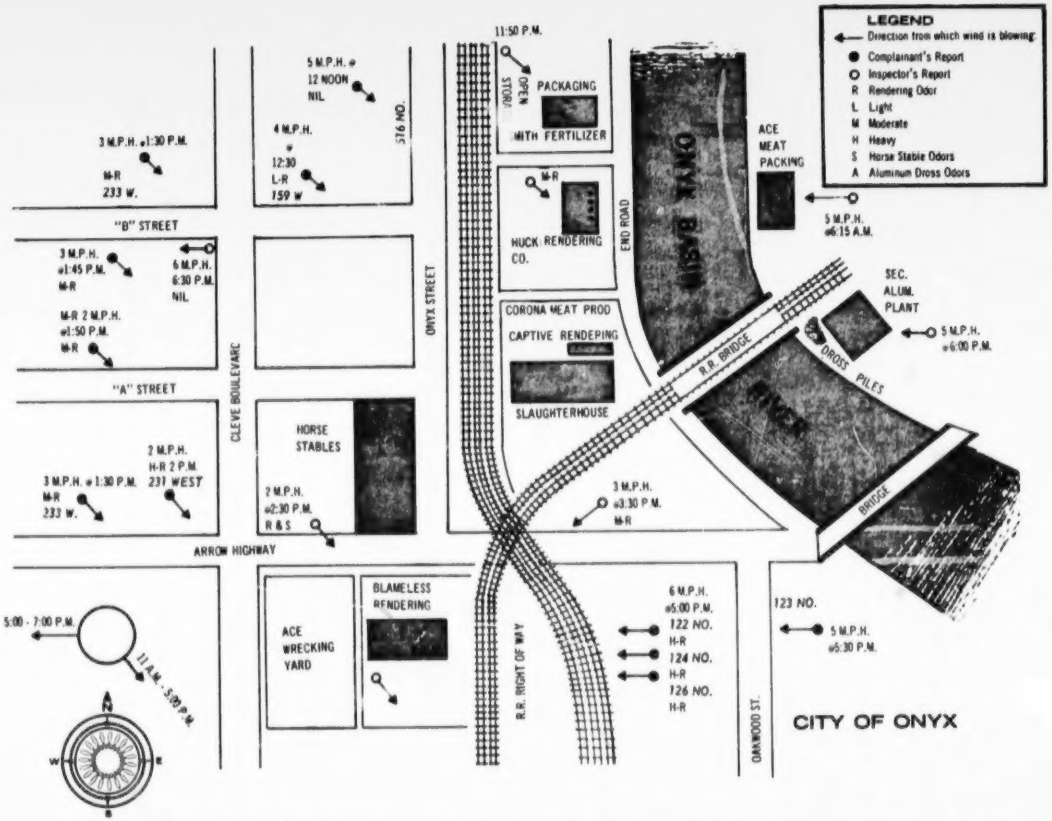

LEGEND
Direction from which wind is blowing
● Complainant's Report
○ Inspector's Report
R Rendering Odor
L Light
M Moderate
H Heavy
S Horse Stable Odors
A Aluminum Dross Odors
ONYX BASIN
RIVER
R.R. BRIDGE
BRIDGE
ACE MEAT PACKING
5 M.P.H. @6:15 A.M.
SEC. ALUM. PLANT
DROSS PILES
5 M.P.H. @6:00 P.M.
11:50 P.M.
OPEN STORA
PACKAGING
SMITH FERTILIZER
M-R
HUCK RENDERING CO.
END ROAD
CORONA MEAT PROD
CAPTIVE RENDERING
SLAUGHTERHOUSE
3 M.P.H. @3:30 P.M. M-R
ONYX STREET
R.R. RIGHT OF WAY
5 M.P.H. @ 12 NOON NIL
4 M.P.H. @ 12:30 L-R 159 W
516 NO.
3 M.P.H. @1:30 P.M. M-R 233 W.
"B" STREET
3 M.P.H. @1:45 P.M. M-R
6 M.P.H. 6:30 P.M. NIL
M-R 2 M.P.H. @1:50 P.M. M-R
"A" STREET
CLEVE BOULEVARD
HORSE STABLES
2 M.P.H. @2:30 P.M. R & S
2 M.P.H. H-R 2 P.M. 231 WEST
3 M.P.H. @ 1:30 P.M. M-R 233 W.
ARROW HIGHWAY
BLAMELESS RENDERING
ACE WRECKING YARD
6 M.P.H. @5:00 P.M. 122 NO. H-R 124 NO. H-R 126 NO. H-R
OAKWOOD ST.
123 NO.
5 M.P.H. @5:30 P.M.
CITY OF ONYX
5:00 - 7:00 P.M.
11 A.M. - 5:00 P.M.
N
W
E
S

Figure 6.5.5. ODOR SURVEY. Although possibly malodorous industries are centered between Onyx St. and End Road and along the Onyx Basin River, reports and observations indicate that the Blameless Rendering Company is the primary source of the odors. This finding is verified by the fact that complaints are reported in two time periods--from 11:00 A.M. to 5:00 P.M., from residents north of Arrow Highway and west of Onyx Street, when the wind was from the southeast, and from 5:00 to 7:00 P.M., from residents in the area around Oakwood Street, south of Arrow Highway, when the wind was from the west. Inspection reports, operating data and point observations verify the existence of a public nuisance at the Blameless Rendering Company. (SOURCE: Weisburd, Reference 14.)

potential on his reports in the event that complaints are received regarding that type of odor.

In most odor problems tracking is unnecessary. An experienced investigator is often able to identify the source of an odor by its quality and intensity and may be able to relate the odor to a specific activity. Since enforcement officers are familiar with the industrial establishments in their inspection sectors, they are often able to connect the odor with a specific piece of equipment.

The enforcement officer verifies his findings by following an odor route in order that he may prove that the odor emanates from a specific piece of equipment. In such tracking situations it is not necessary to rate odors numerically, but to describe the odors as they are perceived. In these cases the inspector either follows the odor from the suspected source as it moves downwind to effect areas, or he proceeds from an effect area (i.e., from the complainants themselves) upwind to the source. The first method is for verification, the second for tracking an unknown source.

(1) Point Observations

The purpose of tracking odors or making odor surveys is (1) to locate an unidentified source of an odor, and (2) to prove to the satisfaction of the courts that a given odor results from a contaminant emanating from a specific source or sources. The proof can only be made by an expert witness, the investigator, familiar with odors and the equipment and operations located in a suspected area.

In some cases, a recognized odor may be attributed to a single source, if there is known to be only one activity in the established source area capable of emitting the odor. If the circumstances are less auspicious, the recent operating experience of several suspect sources may require investigation. Inventory and permit records at the enforcement agency may be consulted to locate all potentially suspect equipment in the source area.

The consensus of odor quality in the complaint area must be identical to the odor quality emanating from the source. That is, with the exception of "intensity" all significant point observations should agree. The "intensity" should vary in a geographical pattern. A point observation here is a stationary location at which an evaluation was made of the following:

- Odor quality and intensity.
- Wind direction and strength at time of odor.
- Duration of odor.
- Time of day and date.

Each nuisance complaint represents a point of observation. Either the investigator verifies the complainant's information, or if there are so many complainants that he cannot do so, he requests the complainant to keep a record of this information. The pattern of complaints may thus, in itself, delineate a vector which will point upwind to the source. Especially is this true when complainant locations form a circle or a crescent on a map, when odors are reported under relatively stable weather conditions. The projected center of any circular locus of point observations can be assumed to be the source area.

Where an insufficient number of point observations are disclosed, scheduled point observations may be conducted to triangulate the source. At such point observations, the investigator may, when odors are detected, make use of the scentometer described previously or take several samples of the air with evacuated flasks. One flask can be used for comparison purposes in an odor-free room at the enforcement agency and another for lab analysis of the odorants. For even more effective analysis, odorants can be sampled from the atmosphere at point observations by activated carbon sorption or by freeze-out trapping; analysis can then be made by infrared or mass spectrometry.

(2) Micrometeorological Problems

Several complications with respect to odors due to the micrometeorology of given areas may arise. The distances and elevations at which odor travels may be very considerable. Sour gas odors from oil fields have traveled as much as 100 miles from a source, though this instance is rare. Where meteorological conditions are favorable to odor dissemination, the radius will not generally exceed 5 to 10 miles. Most odors seem to be confined in an area 1/2 to 2 miles in radius during stagnant air conditions. Odor dissipation may depend on temperature, humidity, wind velocity and steadiness of prevailing wind.

Some estimate of wind velocity may be useful in determining relative distances at which a source might be located from the complaint area. A weak breeze, for example, suggests that a source may be nearby, since a slow moving odor stream may dissipate by diffusion before it is carried very far. If the breeze is strong, on the other hand, and no suspected sources are nearby, the odor may have traveled a long distance, especially if it is a particularly pervasive odor.

The tracking of an odor from a complaint area to a source is a matter of following an increasing intensity of a given quality of odor. This can be accomplished by making representative point observations along the odor route. To avoid odor fatigue, field officers may travel with their vehicle windows closed to maintain as relatively odor-free vehicle as possible, then open them upon arrival at a new point observation for purpose of comparison.(12)

Actual "skips" in the odor route may be observed due to local turbulence, eddies, etc. Odorants may also travel in air streams at varying elevations above the ground, then strike a neighborhood or community situated on a rise of land.

To positively establish an "odor route," Gruber(11) suggests the use of balloons to plot low-level wind directions along the path of the wind itself. He suggests partially inflating such balloons with helium gas so that they will rise slowly and indicate a low-level wind direction which can be plotted with a compass and recorded on a map.

(3) Approaching the Plant

The investigator in tracking problems travels towards the plant on its downwind side and notes the intensity of the odor. In more complicated cases, several radio-equipped cars are deployed to transmit intensities which are then recorded and interpreted at the communication center. Several cars may be necessary when the odor fluctuates, the wind direction changes, or a complex of possible sources in an area makes positive identification of a source difficult.

If the odor is traced to an industrial community and to a group of industrial plants all performing similar industrial operations, it will be necessary to determine whether all of the plants, a few, or just one plant is responsible. Because the responsibility must be clearly determined, a studied surveillance of the inside and outside of each suspected plant may be required. Action can be taken against multiple sources, as well as single sources, as long as the odor concentration arising from each, and together, can account for the intensities noted.

If the odor is not chronic, and was reported for the first time, it may be due to deviation in operational practice, to a breakdown of equipment or to the introduction of a new process. Because of these probabilities, a one-time odor is likely to originate from one industrial source. An inspection of the plant may disclose the specific operation which has caused the nuisance. When the odor has been traced to the equipment, the conditions under which the malodorous contaminants were emitted must be fully documented.

Although the odors which are detected in the field arise from the diffusion of gases and vapors, the source of the odors may be in solid or liquid form. Samples of petroleum products, chemical fluxes, solvents, decomposed organic matter, materials from open dumps, etc., can be taken as evidence, or the material can be photographed. The fact that substances may have vapor pressures sufficient to yield an odor or have low odor thresholds can be substantiated by expert testimony, as long as other operational and conditioning factors which caused the odor are reported.

F. INVESTIGATION OF ODOR POTENTIALS OF SOURCES

During the inventory inspection at industrial plants, field officers normally attempt to initiate corrective steps on processes entailing potential odor problems, in order to prevent nuisances.

1. Plant Inspection and Source Testing(13)

On suspicion of odor nuisance emissions, plant inspection may be undertaken, supplemented by source testing for evaluation of the odor potential. As soon as practical after identifying the suspected source of odor emissions, the field officer should proceed to gain entry into the plant for the purpose of: (1) gathering the evidence needed to prove that the violation has occurred, namely that: a person discharged into the atmosphere, from a single source, a contaminant in greater amount or quality than allowed for more than the specified time; (2) determining the cause; and (3) ascertaining the necessary corrective measures.

In some of the larger control agencies the inspection is carried out by two levels of staff. Item (1), above, is the responsibility of the field patrol; while items (2) and (3) are assigned to engineering inspectors. In the smaller agencies, one man must carry out all three investigations.

After gaining entry, the investigator should seek the highest ranking person he can reach who will have intimate knowledge of the plant operations and who has authority to speak for the company management.

a. Interrogation

By proper interrogation, the field officer should establish the circumstances leading to the emission violation. He should be alert for observations he can make to verify the truthfulness and accuracy of the statements made to him. For example, a common cause of dense smoke emission is rodding a stoker-fired boiler. If this has occurred and the inspection immediately follows the observation, the firing bar will be warm. A simple check is to feel the firing bar.

b. Equipment Data

Next, the equipment data is obtained unless it is, to the inspector's knowledge, already a part of the plant record. This should include the make, type, size, and capacity of all equipment or processes involved. Note should also be made of general conditions which have a bearing on the air pollution potential of the equipment. Observations should be made of gages and monitoring instruments, particularly temperature charts on odor incinerators, load charts on boiler instrument panels, photoelectric opacity recorders, etc. Information on operating failures which lead to excessive emissions are being published in the technical literature. Much benefit can be gained from process studies which point out operating conditions which cause high pollution discharge.

2. Evaluating Odor Concentrations

Where the odor being investigated has been identified as caused by a known odorant it should be measured by chemical or physical means in the laboratory. This is especially true when the known odorant also has toxic or irritant potential, as in the case of hydrogen sulfide, sulfur dioxide, ammonia, chlorine, various aldehydes and some other organic and inorganic compounds. In many such cases, the criteria for acceptable concentrations in ambient air are already established in terms of mass concentrations which are lower than odor thresholds, so that evaluation in terms of odor units is superfluous.

However, when the odor nuisance is the only suspected effect, or whenever the identity of the odorant is in doubt, or more specific methods of measurement are unavailable, the samples collected at the source should be evaluated by an odor panel using dilution techniques, as described previously.

G. RELATING SOURCE STRENGTH TO CONTROL REQUIREMENTS

In correcting an odor problem, the contaminants responsible for an odor should be controlled so that threshold levels are never reached in the outdoor atmosphere of the community. Some industries incorrectly assume that they will have no odor problems, because they consider their own discharges to be unobjectionable or even pleasant. However, the presence of any odor which persists and is not normally associated with the daily routine of living will be a source of annoyance to the neighborhood. Complaint records show that this applies to such comparatively acceptable odors as those of baking bread and roasting coffee; therefore, it is wise to consider any odor as potentially objectionable.

The odor evaluations of source samples provide estimates of odor concentrations in terms of odor units per unit volume, which can serve as guidelines in the development of control methods. Thus, if a stack effluent is normally diluted by a factor of 1,000 before it arrives at a breathing level in the surrounding neighborhood, an odor concentration of 1,000 odor units per standard cubic foot could be considered to be on the verge of acceptability, while an odor concentration of 10,000 would require at least 90% control.

This sort of guideline can be refined by calculating an odor emission rate in odor units per minute. This is equal to the product of the odor concentration by the volume rate of the stack exhaust, in standard cubic feet per minute (scfm). Table 6.5.1 illustrates some examples of typical results using this approach (as reported by Benforado, et al.(10)).

Dilution factors required for positive control can be estimated either by surveying ambient air in the vicinity to determine the maximum odor concentrations observable, or by standard engineering design procedures based on plume dilution equations or community experience. It should, of course, be remembered that dilution of odorous gas to the median odor threshold level can be expected to render it undetectable by only about half of the people in the community; therefore the use of an additional safety factor in design for positive control is ordinarily advisable. Also, dilution factors work better near the source and tend to break down with distance.

An application of odor measurement in improving neighborhood odors would be to survey all the operations in a plant and determine the odor emission rate from each. Listing such emissions together with estimates of costs for control can help management pick out the largest odor sources (rather than the largest stacks or largest volume discharges) and concentrate effort initially on those which are likely to provide the greatest improvement per dollar of expenditure.(6)

Table 6.5.1. MISCELLANEOUS TESTS: RENDERING PLANT; COFFEE ROASTER; RUBBER PROCESSING PLANT

Application	Exhaust Flow (scfm)	Average Odor Strength (odor units/scf)	Average Emission Rate (odor units/min)	Remarks
Rubber processing	6900	50	350,000	Acceptable—controlled by direct-flame fume incinerator
Coffee roaster	3600	2000	7,200,000	Not acceptable—uncontrolled effluent from roasters
Rendering plant	29,000	1500 - 25,000	55,000,000 730,000,000	Not acceptable—uncontrolled effluent from dryer

H. ODOR CONTROL

The elimination of odors is the most important part of any odor problem. Air contaminants responsible for an odor should be controlled so that threshold concentrations are never reached in the outdoor atmosphere. This is accomplished by adopting any one or a combination of control devices or techniques such as waste gas incinerators, catalytic oxidation, and adsorption in activated carbon. Such common-sense control methods as general sanitation, refrigeration of animal tissue, improved maintenance and operational techniques should also be applied where odors arise from plant housekeeping.

The abatement of odors is accomplished either by complete destruction of odorants and prevention of odorant emissions, or neutralizing the malodorous effects of contaminants. Odor prevention or odor destruction is generally preferable since air pollution control in critical pollution areas seeks control of contaminants, not the effects of contaminants. For this reason, the ideal odor control method is perfect combustion. This is accomplished by an afterburner or waste gas incinerator. To be effective, such devices must maintain complete combustion at proper temperatures and exposure times, reducing all contaminants to odorless water and carbon dioxide. Partial or incomplete combustion may result in a series of reactive secondary products which may not only be malodorous, but eye-irritating and corrosive as well.

Other methods of preventing the escape of odors to the atmosphere include chemical scrubbing and charcoal filtering described in other Sections of this Manual.

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VI. MOTOR VEHICLE VISIBLE EMISSIONS

A. INTRODUCTION

Motor vehicles make up by far the largest source of transportation emissions and in some urban areas are the predominant contributor to total air pollution. Collectively, motor vehicles emit large quantities of particulates, carbon monoxide, hydrocarbons and oxides of nitrogen (see Section II, Chapter 1).

The control of motor vehicle emissions ultimately depends on technological solutions leading to the mass production of low-emission vehicles. Current approaches include:

(1) Engine exhaust control systems such as blow-by gas recycle, catalytic converter and exhaust gas recirculation systems.

(2) Engine modifications including manifold air injection and adjustment of ignition timing and air-fuel mixture.

(3) Evaporative controls for fuel systems.

(4) Alternative propulsion systems such as electric battery, gas turbines and rotary engines.

(5) Alternative fueling systems including liquified natural gas (LNG) or liquified petroleum gas (LPG).

Beginning with the 1968 model year, all new passenger vehicles, both foreign and domestic, had factory installed exhaust control and closed crankcase control systems in compliance with Federal law.

Enforcement of regulatory standards affecting motor vehicles can be accomplished in three distinct ways: (1) systematic inspection and testing of motor vehicles initially at assembly plants and periodically at official inspection stations to ensure that vehicles are maintained within acceptable ranges of air pollution control system effectiveness; (2) spot-checking of vehicles for defects or disconnected control systems usually performed by state highway patrols or police agencies as part of an overall vehicle safety check; (3) surveillance of moving behicles for violations involving excessive emissions conducted by law enforcement officers or air pollution control field enforcement officers. Field enforcement includes inspection of vehicle control systems to see that they are installed, connected and in operation.

Field enforcement officers in air pollution control agencies perform functions related primarily to (3) above. Enforcement practices among agencies may vary from no activity in this area to an organized vehicle surveillance and enforcement program conducted by a special vehicle patrol unit operating within the enforcement branch of the agency. Two types of motor vehicles are basically involved: the gasoline powered and diesel-powered vehicles.

B. GASOLINE-POWERED VEHICLES

In addition to their contribution to background pollution, gasoline-powered vehicles are important because they are dispersed with the general population, and pedestrians and drivers are directly exposed to both visible and nonvisible emissions.

Motor vehicles that are maintained in good condition and are normally operated should not emit visible emissions. Visible emissions may result from:

(1) Poor engine condition, engine not tuned properly, worn plugs, valves and rings and faulty choke mechanism, timing and carburetor settings.

(2) Abnormal driving practices including operation of the vehicle in a manner that results in rapid acceleration or deceleration under load and speed shifting.

(3) Unorthodox fuels or use of engine and fuel additives to "clean-out" the engine.

(4) Unorthodox engine modifications.

(5) Disconnection or corruption of vehicle pollution control systems.

(6) Deterioration of control systems on aged or poorly maintained vehicles.

(7) Various combinations of the above.

1. Vehicle Emission Control Systems(1)

Typical vehicle emission control systems that may be checked by field enforcement officers include the following:

a. Crankcase Control Devices

(1) Type 1: Open system; valve controlled by intake manifold vacuum; approved when factory installed on 1961 through some early 1964 models. This type of system is shown in Figure 6.6.1.

(2) Type 2: Valve controlled by crankcase vacuum; approved for both factory and station installation (Figure 6.6.2).

(3) Type 3: Tube-to-air cleaner; no devices approved for station installation (Figure 6.6.3).

(4) Type 4: Combination system; approved for both factory and station installation (Figure 6.6.4).

b. Exhaust Control Systems

These are intended to control emissions from the engine exhaust either by promoting combustion at the engine exhaust ports or manifold or in the exhaust system, or by modifying engine operation

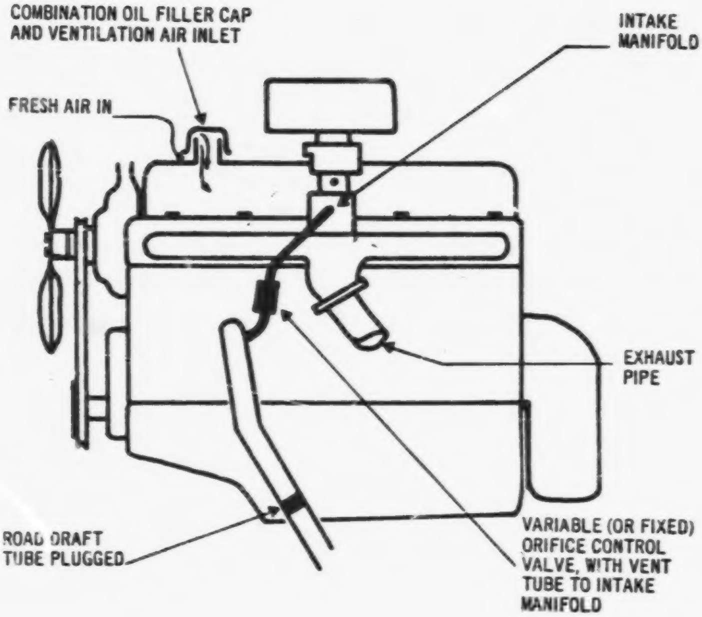
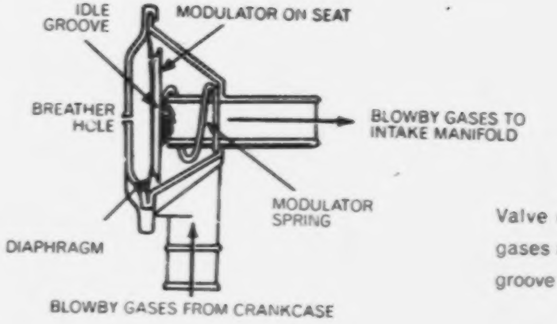
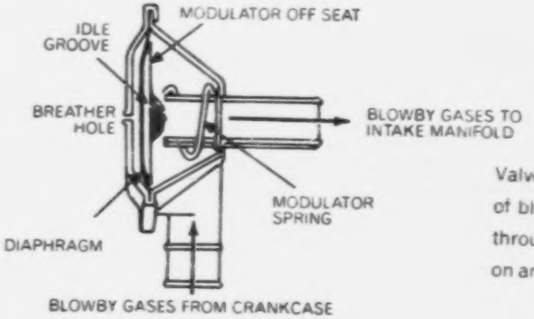

COMBINATION OIL FILLER CAP AND VENTILATION AIR INLET
INTAKE MANIFOLD
FRESH AIR IN
EXHAUST PIPE
ROAD DRAFT TUBE PLUGGED
VARIABLE (OR FIXED) ORIFICE CONTROL VALVE, WITH VENT TUBE TO INTAKE MANIFOLD

Figure 6.6.1. CRANKCASE VENTILATION SYSTEM USING VARIABLE ORIFICE CONTROL VALVE (TYPE 1) (SOURCE: CALIFORNIA HIGHWAY PATROL, Reference 1)


IDLE GROOVE
MODULATOR ON SEAT
BREATHER HOLE
BLOWBY GASES TO INTAKE MANIFOLD
MODULATOR SPRING
DIAPHRAGM
BLOWBY GASES FROM CRANKCASE

Engine at idle

Valve closed, modulator on seat. Blowby gases and ventilating air flow through idle groove at about 3 cfm.


IDLE GROOVE
MODULATOR OFF SEAT
BREATHER HOLE
BLOWBY GASES TO INTAKE MANIFOLD
MODULATOR SPRING
DIAPHRAGM
BLOWBY GASES FROM CRANKCASE

Engine at cruise

Valve open, modulator off seat. Larger volume of blowby gases and ventilating air now flow through valve. Flow rate of valve dependent on amount of blowby generated by the engine.

Figure 6.6.2. VALVE CONTROLLED BY CRANKCASE VACUUM (TYPE 2)
(SOURCE: CALIFORNIA HIGHWAY PATROL, Reference 1)

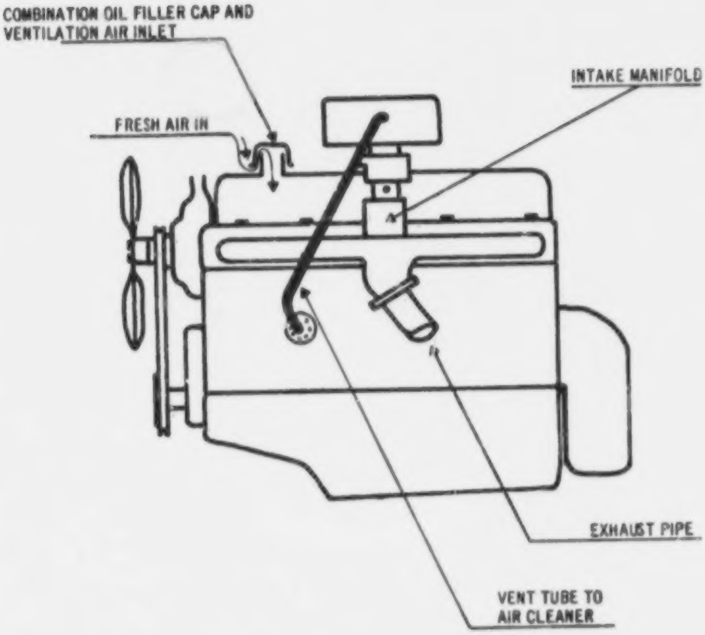

COMBINATION OIL FILLER CAP AND VENTILATION AIR INLET
INTAKE MANIFOLD
FRESH AIR IN
EXHAUST PIPE
VENT TUBE TO AIR CLEANER

Figure 6.6.3. CRANKCASE VENTILATION SYSTEM USING A VENT TUBE TO THE AIR CLEANER (TYPE 3) (SOURCE: CALIFORNIA HIGHWAY PATROL, Reference 1)

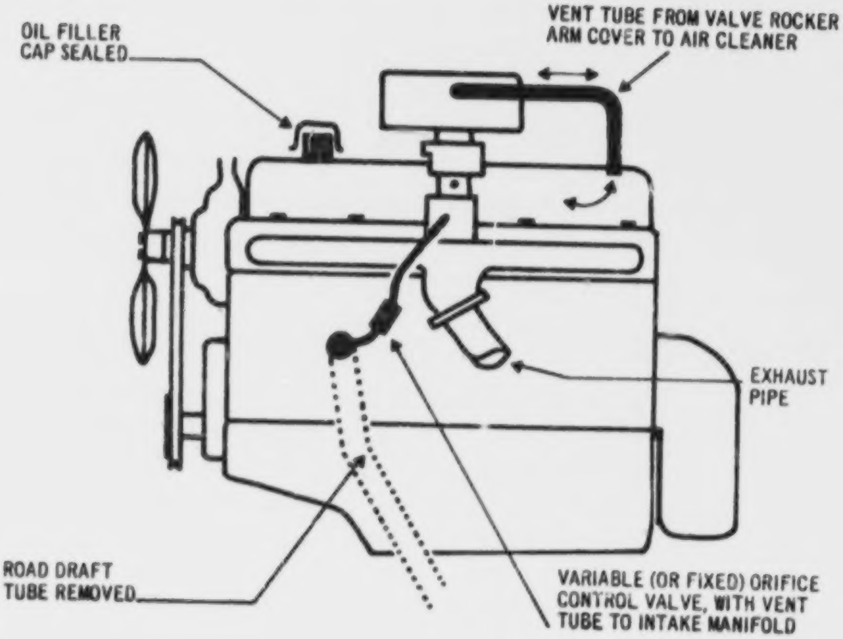

OIL FILLER CAP SEALED
VENT TUBE FROM VALVE ROCKER ARM COVER TO AIR CLEANER
EXHAUST PIPE
ROAD DRAFT TUBE REMOVED
VARIABLE (OR FIXED) ORIFICE CONTROL VALVE, WITH VENT TUBE TO INTAKE MANIFOLD

Figure 6.6.4. SCHEMATIC VIEW OF COMPLETELY CLOSED TYPE CRANKCASE VENTILATING SYSTEM (TYPE 4) (SOURCE: CALIFORNIA HIGHWAY PATROL, Reference 1)

so that air and fuel supplied results in combustion with reduced hydrocarbon and carbon monoxide emissions. Vehicle control system types include air injection, ignition induction, and various variations of these including the Engine-Mod System (American Motors), Improved Combustion Control (IMCO) on certain Ford Motor Company models and the CCS or Controlled Combustion System on several General Motors cars.

(1) Air Injection Systems

These typically consist of: air pump, air injection into each exhaust port, and carburetor and distributor modifications. Typical systems for 6 and 8 cylinder engines are shown in Figures 6.6.5 and 6.6.6.

(2) Engine Modification Exhaust Emission Control Systems

Examples of modified engine components include combustion chambers altered in shape to decrease quench area, an intake manifold redesigned to achieve complete vaporization of the fuel, and a fuel injection system which replaces the carburetor and allows leaner running.

Engine-modification type exhaust control systems usually include minor charges such as a deceleration control device, leaner carburetion, retarded spark at idle, and may include a thermostatic valve for spark advance and an anti-dieseling solenoid (see Figures 6.6.7 and 6.6.8).

c. Fuel-Evaporative Control Systems

All 1970 and later model gasoline-powered passenger and light duty commercial vehicles first sold and registered in California and having an engine displacement of 50 cubic inches or greater must

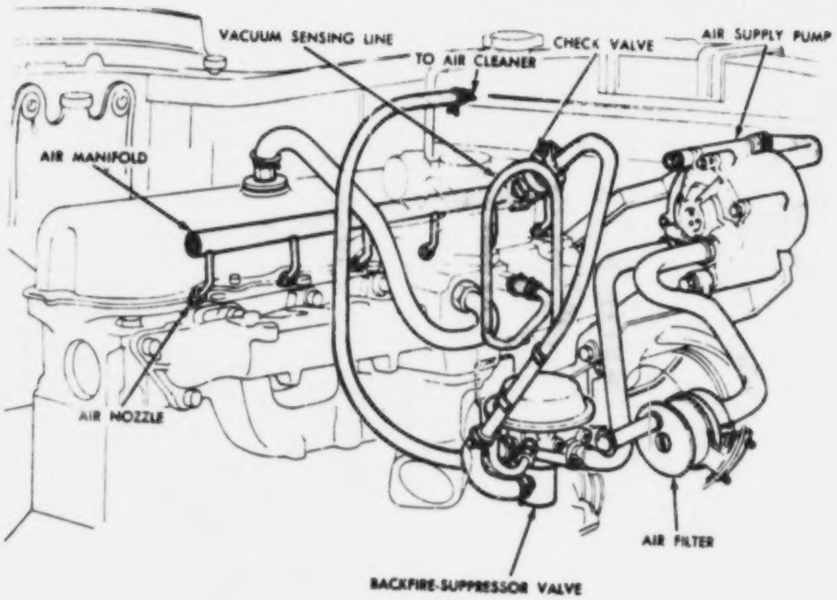

VACUUM SENSING LINE
TO AIR CLEANER
CHECK VALVE
AIR SUPPLY PUMP
AIR MANIFOLD
AIR NOZZLE
AIR FILTER
BACKFIRE-SUPPRESSOR VALVE

Figure 6.6.5. 6-CYLINDER ENGINE AIR INJECTION SYSTEM
(SOURCE: CALIFORNIA HIGHWAY PATROL, Reference 1)

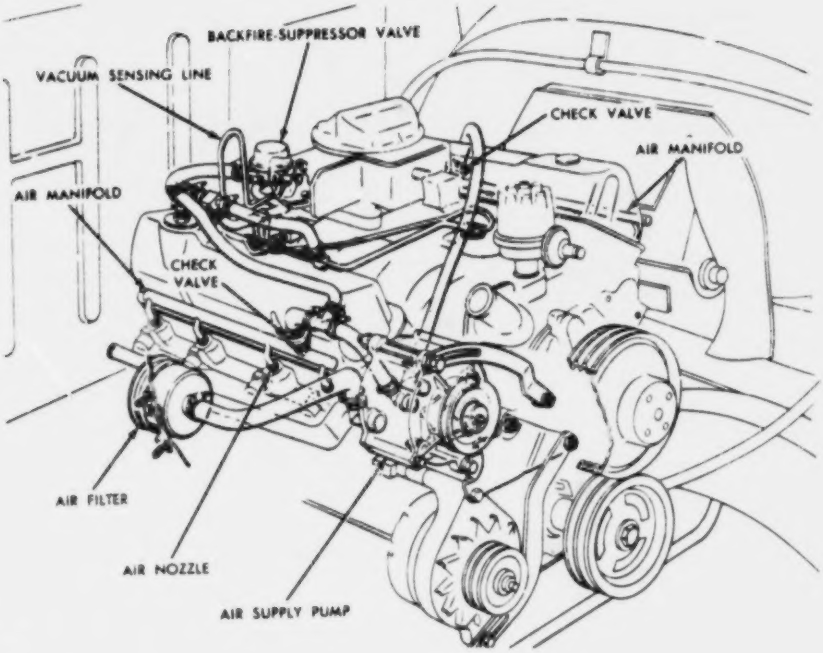

BACKFIRE-SUPPRESSOR VALVE
VACUUM SENSING LINE
CHECK VALVE
AIR MANIFOLD
AIR MANIFOLD
CHECK VALVE
AIR FILTER
AIR NOZZLE
AIR SUPPLY PUMP

Figure 6.6.6. V-8 ENGINE AIR INJECTION SYSTEM (SOURCE: CALIFORNIA HIGHWAY PATROL, Reference 1)

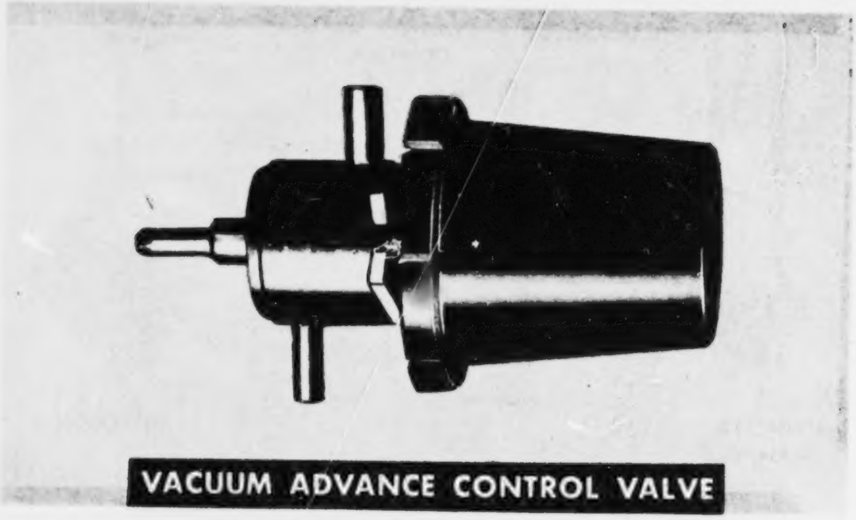

VACUUM ADVANCE CONTROL VALVE

Figure 6.6.7. VACUUM ADVANCE CONTROL VALVE (SOURCE: CALIFORNIA HIGHWAY PATROL, Reference 1)

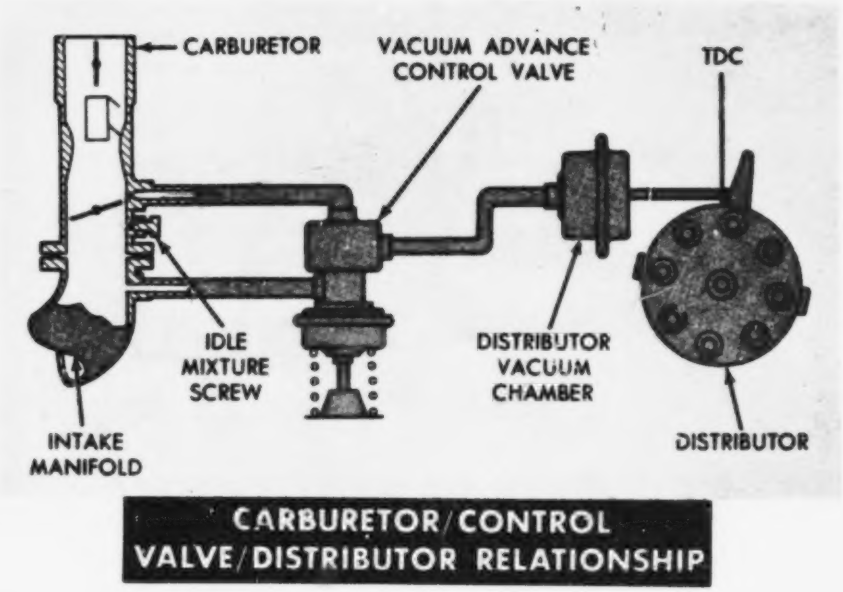

CARBURETOR
VACUUM ADVANCE CONTROL VALVE
TDC
IDLE MIXTURE SCREW
DISTRIBUTOR VACUUM CHAMBER
INTAKE MANIFOLD
DISTRIBUTOR
CARBURETOR/CONTROL VALVE/DISTRIBUTOR RELATIONSHIP

Figure 6.6.8. CARBURETOR/CONTROL VALVE/DISTRIBUTOR RELATIONSHIP (SOURCE: CALIFORNIA HIGHWAY PATROL, Reference 1)

be equipped with a fuel evaporative loss control device or systems. These systems are intended to prevent evaporative losses from the entire fuel system including the gas tank, the fuel filter valve, breathing vents and carburetor. A typical system is shown in Figure 6.6.9.

2. Types of Visible Vehicle Emission Violations

a. Nuisance Type Violation

The principal criterion in halting and citing gasoline-powered vehicles is primarily one of nuisance. This may be taken to mean the emission of any quantity of smoke which is outstanding in terms of volume, color, and duration as to draw attention to the offending vehicle. In traffic conditions such smoke is likely to result in fumigating other vehicles on the roadway and to offending drivers and pedestrians who are not in a position to avoid the emissions or to register a formal complaint.

Some enforcement agencies have power to cite excessive emissions under a general nuisance law or a specific nuisance type regulation directed at this type of source. For example, the Motor Vehicle Code of the State of California states that "no motor vehicle shall be operated in a manner resulting in the escape of excessive smoke, flame, gss, oil, or fuel residue." The enforcement officer must precisely describe the character of the "excessive" emission in each situation, e.g., volume of smoke emitted, opacity, effect of emissions on other vehicles, and likely cause of the emissions. If the smoke plume obscures the traffic area, is continuous through more than one gear, is outstanding, or is a nuisance, action can be taken under this criterion. This approach is generally suitable for privately owned passenger vehicles. Examples of a citation form is illustrated in Chapter 2.

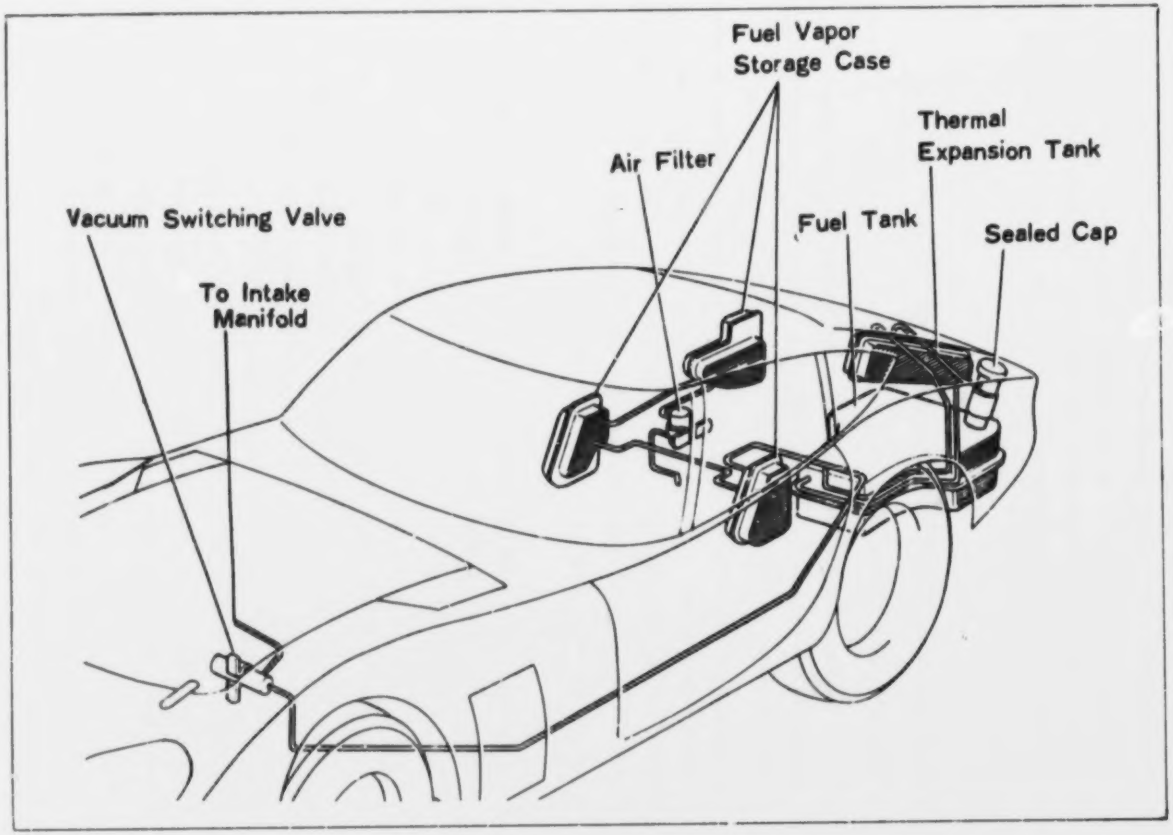

Fuel Vapor Storage Case
Thermal Expansion Tank
Air Filter
Vacuum Switching Valve
Fuel Tank
Sealed Cap
To Intake Manifold

Figure 6.6.9. EVAPORATIVE LOSS CONTROL SYSTEM--VAPOR STORAGE CASE USED BY TOYOTA (SOURCE: CALIFORNIA HIGHWAY PATROL, Reference 1)

b. Opacity-Type Violation

Another form of vehicle violation is based on the principles of reading emissions from stationary sources, e.g., application of Ringelmann, opacity and time criteria (see Chapter 4, Section III). The enforcement officer uses the accumulative stop watch method by totaling the periods of time in which Ringelmann densities exceed the prescribed standard (see Chapter 2). The observer following a vehicle must avoid reading directly into the plume, if possible. The line of observation should intersect the smoke train at as wide an angle as possible. Error of reading smoke in this fashion should be compensated for and smoke should be read at its point of maximum density.

Recommended rules for gasoline-powered motor vehicles limit visible air contaminants to five seconds.(2)

The opacity-type violation is suitable for commercial vehicles and is handled in a manner similar to stationary sources (see Chapter 2). The commercial operator tends to own more than one vehicle, and to have the resources to institute a preventive maintenance program for all of his vehicles. For this reason, the violation notice route provides the options to either prosecute the case in court and/or to provide opportunity (through the administrative conference process) for the owner to correct his problem with the specific vehicle, or to institute a maintenance program for all vehicles, and to train individual operators. These procedures may also provide for increasing penalties for repeated violations either of the same vehicle or other vehicles. It is sometimes desirable to include an additional inspection report where the enforcement officer has determined the causes of the violation from remarks made by the operator or from inspection of the equipment.

3. Following and Halting of Vehicles

In some control jurisdictions enforcement officers may not be authorized to stop vehicles. License numbers are taken, and the owners and/or operators are sent warning letters, or are requested to attend an office hearing. In some regions private and commercial vehicles are halted and detained on the road. In the latter case, special conditions and rules of the road apply.

In performing vehicle patrol it is desirable to conduct systematic patrols of expressways, freeways, major arteries, secondary and residential streets. It is undesirable to patrol congested areas where it is impractical to halt vehicles, or where the halting of such vehicles presents hazards to the driver, to others and to the enforcement officer. It is sometimes desirable to identify certain road segments that can be observed which allow comparison of emissions of vehicles operating under the same road conditions, and where shoulders or other safe places to pull cars off the road are known to be present. Such roadways may include signals or stop signs, long sections of smooth traffic flow and inclines or hills which permit observation of vehicles operating under load. Two officers should ride in each patrol care. One procedure(3) includes the following:

a. Go to area as directed.

b. Avoid road hazards, police radar sites, etc., or other impediments which may interfere with the observation and pursuit of vehicles.

c. Select an observation point in a level area with wide shoulders.

d. Clock off a distance of at least 90 yards between two known points (e.g., overpasses).

e. Observe for violators. Pull out and follow only if it is safe to do so.

f. Follow over the clocked course, observing the smoke constantly.

g. At a safe place overtake and flash red light; the second officer holds out badge.

h. Use police procedures in approaching the other vehicle.

i. The enforcement officer takes the registration and completes the notice or report. The other compares the registration number with the license plate of the vehicle.

j. One of the enforcement officers takes the driver's license and fills out the notice, summons, or citation. They then trade license and registration and terminate the apprehension. The license is generally not returned until the citation has been written. The driver should be detained as little as possible. The enforcement officer should listen more than talk, particularly for any admission from the driver.

Certain types of vehicles may be exempt from being detained, particularly vehicles which are impractical to halt or which may involve legal difficulties such as the halting of passenger-carrying buses. The license number and bus owner (when painted on the side of the vehicle) can be taken, however, for handling of the violation by mail.

Every effort should be made to halt motor vehicles with complete regard to the rules of the road as defined in the state vehicle code or elsewhere, and to the safety and protection of other motorists using the highway. In all cases the halting of a motor vehicle should be accomplished by at least two enforcement officers riding in an emergency type vehicle, appropriately marked and equipped with red lights and siren.

If the vehicle which the officer is observing refuses to stop, the officer writes down the vehicle license number, cab number or other identification of the vehicle and observes the driver for the purpose of later identification in court, if necessary. A full written report of the occurrence is then made by the officer to his supervisor. This information may be sufficient to warrant the issuance of a complaint.

C. EMISSIONS FROM DIESEL-POWERED VEHICLES

1. Cause of Diesel Emissions

Emissions from diesel-powered vehicles presents certain problems which differ from gasoline-powered vehicles, namely: (1) diesel-powered vehicles tend to produce both smoke and odors due to the nature of the diesel fuel; (2) although diesel engines can be operated in a smokeless condition, they have a greater tendency to smoke during full throttle acceleration, under load, or from "lugdown" from maximum governed speed, at full throttle; (3) the color of the emissions may be white, blue, or black, with black more commonly observed; (4) the plume may be continuous and long and the volume of smoke and particulates emitted fairly large; (5) odors associated with unburned and partially burned organic material contained in the smoke, together with the smoke, tend to cause frequent complaints; (6) the engine design parameters contributing to the smoke emissions differ from gasoline-powered vehicles; (7) diesel engines may require a greater degree of maintenance from the standpoint of extent of use, emission reductions, and should be more carefully operated particularly when such vehicles pass through metropolitan areas. The smoke emissions appear to be related to engine power requirements. New smoke standards require that new engines be adjusted by the engine manufacturer to a conservative fuel rate and power output.

Like gasoline-powered vehicles, diesel-powered vehicles should not be cited where emissions occur from engines which have been reasonably operated and maintained, i.e., where emissions are due to the inherent design of the diesel engine. This is an R&D problem affecting control of all diesel-powered vehicles. Tractors climbing steep inclines under heavy loads may tend to smoke excessively even with careful operation. The enforcement officer must be trained to recognize vehicles which for any given type of road and traffic condition and engine selection is smoking excessively due to negligent operation and maintenance of the vehicle. This training is possible only with experience in the field. The following inspection points (4.5) may be noted:

(1) Overfueling an engine causes an unbalanced air-fuel ratio. Each engine or model of engine is designed to burn a given amount of fuel per hour for its rated horsepower. Any amount above will increase the exhaust smoke.

(2) Intake air system - The intake air system determines whether the engine is getting sufficient air to maintain proper air-fuel ratio. Dirty air cleaners restrict air flow, rubber hose connections that have collapsed, restricts the air flow. Too high an oil level in the air cleaner restricts air flow. Air cleaners mounted under hoods or in places where the air temperature is much higher than ambient, also restricts the quality of air needed.

(3) Low compression has a leading role in creating excessive smoke. The chief causes of low compression come from rings not seating or worn rings and liners and poor seating of valves. Either, or both of these, cause low compression which in turn causes poor combustion and smoke.

(4) Faulty fuel systems, poor or improper metering of fuel, faulty spray nozzles and use of poor grades of fuel that do not meet engine manufacturers specifications, contribute to smoke formation.

(5) Faulty exhaust systems, either by incorrect piping or by defective muffler can and does add to back pressure within the system and increases smoke density.

(6) Black smoke may result from unnecessary rapid acceleration, unnecessary stop-and-go, and speed shifting--all associated with negligent operation. Blue smoke generally results from excessive lubricating oil consumption. This may be expensive to the operator. White smoke occurs only during start-up from cold starts, and is due to unburned fuel.

(7) Diesel engines emit odors which can usually result in complaints from motorists and pedestrians. The specific odorants have not been positively identified, but these appear to fall into the broad category of oxygenates. The two-cycle air-scavenged engine presents the most serious problem. Acceleration following idle and the high torque/mid speed range modes tend to produce the most malodorous emissions. Combustion quenching, poor air utilization and partial oxidation of unburned fuel also contribute to odors.

The control of diesel emissions like the automobile continues to be a matter of research and development, and many unknowns in the relationship between engine design, engine fueling, fuels and emissions must be resolved. Metal additives, particularly barium-based materials have been used with some degree of success as smoke suppressant additives (SSA). These appear to act catalytically by reducing the ignition temperature and hence formation of soot particles. The metal additive is discharged as barium sulfate and in this form has very low toxicity; other barium compounds that may be emitted may possess higher toxicity. The problem of odors is still little understood--catalytic odor control systems employing oxidation catalysts, and odor masking agents have been employed, but with uncertain effectiveness at the present time. Exhaust gas dilution techniques have also been applied, but with questionable effect. (4)

2. Reading Visible Emissions, Halting and Inspection of Vehicles

The principles of reading visible emissions from diesel-powered vehicles are generally similar to those applied to gasoline-powered vehicles, described previously. The vertical stack and the black emissions of diesel exhaust tend to behave more like a stationary source, and Ringelmann, rather than opacity is usually applied. Recommended regulations limit smoke shades or densities equal to or greater than No. 1 Ringelmann or 20 percent opacity for periods not exceeding 5 consecutive seconds.(2) The vehicle patrol officer should in all cases avoid reading into the horizontal plume, and must obtain a clear view of the vertical cross-section of the plume. This will frequently necessitate avoiding reading the plume while driving in the same lane as the vehicle.

Special care must be taken in halting diesel-powered vehicles. Procedures for halting will be dictated by the vehicle code that applies in any given air quality control region. Ideally, enforcement officers should have police powers and should be authorized to use lights and sirens (if they are provided with emergency vehicles). The use of red lights and sirens, however, where authorized should be used sparingly. Flashing of emergency lights is generally sufficient to halt diesel-powered vehicles. The rig should be allowed to find a safe place to pull completely clear of the highway as shown in Figure 6.6.10. Because of the height of the cab it may also be necessary for the driver to step outside in order for the field enforcement officer to interview him properly. The operator's license should be checked as described previously and the cause of the emissions should be determined. In many cases, the driver is familiar with the condition of his vehicle.

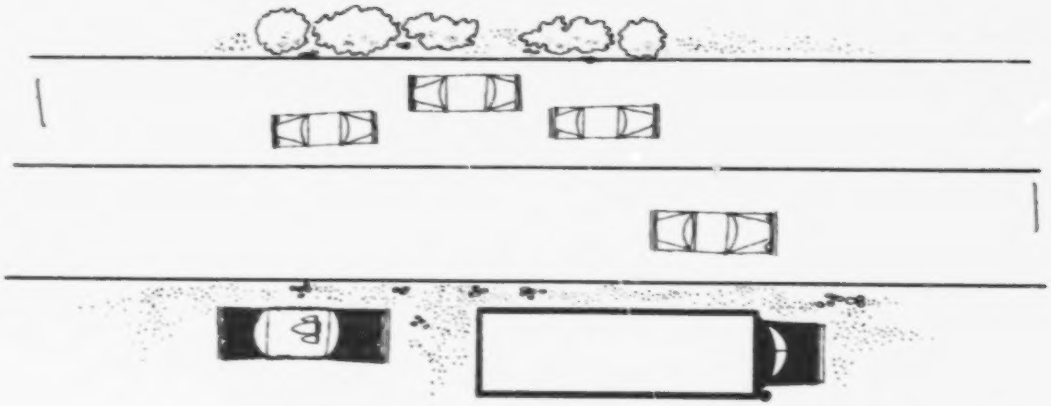


Figure 6.6.10. HALTING OF DIESEL CAB AND TRAILER ON THE HIGHWAY. THE PATROL VEHICLE PULLS BEHIND THE TRUCK, CLEAR OF THE HIGHWAY.

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GLOSSARY

A

ABSORBER: A device utilized to extract selectively one or more elements of a gas stream from others by absorption in a liquid medium. Usually the process is performed in cylindrical towers packed with an inert material thus providing a large surface area for intimate contact between the rising gas and the falling liquid. (The process may also be carried out in a tower containing perforated trays in which the rising gas bubbles through the layer of liquid on the trays.)

ABSORPTION: A process in which one or more constituents are removed from a gas stream by dissolving them in a selective liquid solvent. This may or may not involve a chemical change.

ACCUMULATOR: A vessel for the temporary storage of a gas or liquid; usually used for collecting sufficient material for a continuous charge to a refining process.

ACID SLUDGE: The residue left after treating petroleum oil with sulfuric acid for the removal of impurities. It is a black, viscous substance containing the spent acid and impurities which have been separated from the oil.

ACID TREATMENT: An oil-refining process in which unfinished petroleum products, such as gasoline, kerosene, diesel fuel, and lubricating stocks, are contacted with sulfuric acid to improve color, odor, and other properties.

ACIDULATE: To make acid, especially slightly acid; to treat with acid.

ADDITION REACTION: Direct chemical combination of two or more substances to form a single product, such as the union of ethylene and chlorine to form ethylene dichloride:

$$C_2H_4 + Cl_2 \longrightarrow C_2H_4Cl_2$$

ADIABATIC LAPSE RATE: The rate at which a given mass of air lifted adiabatically (without loss or gain of heat) cools due to the decrease of pressure with increasing height, 5.4°F/1000 ft (9.7°C/km).

ADIABATIC PROCESS: A thermodynamic change of state of a system in which there is no transfer of heat or mass across the boundaries of the system.

ADIABATIC TEMPERATURE: (Combustion) The theoretical temperature that would be attained by products of combustion provided the entire chemical energy of the fuel, the sensible heat content of the fuel, and combustion air above the ambient temperature were transferred to the products of combustion. This assumes (1) that combustion is complete, (2) that there is no heat loss, (3) that there is no dissociation of the gaseous compounds formed, and (4) that inert gases play no part in the reaction.

ADSORPTION: A reaction in which one or more constituents (adsorbates) are removed from a gas stream by contacting and adhering to the surface of a solid (adsorbent). Periodically the adsorbent must be regenerated to remove the adsorbate.

AEROSOL: A colloidal system in which particles of solid or liquid are suspended in a gas. There is no clear-cut upper limit to the particle size of the dispersed phase in an aerosol, but as in all other collodial systems, it is commonly set at 1 micro-meter. Haze, most smoke, and some fogs and clouds may be regarded as aerosols.

AFTERBURNER: A burner located so that combustion gases are made to pass through its flame in order to remove smoke and odors.

AGGLOMERATION: Groups of fine particles clinging together to form a larger particle.

AIR ATOMIZING OIL BURNER: A burner in which oil is atomized by compressed air which is forced into and through one or more streams of oil thus breaking it into a fine spray.

AIR CURTAIN DESTRUCTOR: A device employing an air blower with pit incinerator. Excess oxygen and turbulence result in apparent complete combustion, leaving no residue unburned carbon (smoke) nor odorous hydrocarbons. The device has been satisfactorily demonstrated for disposal of low-ash, high-Btu waste, such as trees, tree trunks, brush (but not leaves), and wooden crating material. Excessive pollution results when materials such as automobile tires, cushions, and other non-wood wastes are burned.

AIR HEATER OR AIR PREHEATER: Heat transfer apparatus through which combustion air is heated by a medium of higher temperature, such as the products of combustion or steam.

ALKYLATION: In petroleum refining, usually the union of an olefin (ethylene through pentene) with isobutane to yield high-octane, branched-chain paraffinic hydrocarbons. Alkylation may be accomplished by thermal and catalytic reactions. Alkylation of benzene and other aromatics with olefins yields alkyl aromatics.

ALUMINA: Aluminum oxide (Al_2O_3), an intermediate product of the production of aluminum. This oxide also occurs widely in nature as corundum.

AMBIENT AIR: That portion of the atmosphere, external to buildings, to which the general public has access.

ANODE: In aluminum production, the positively charged carbon terminal in the reduction cell or pot. Oxygen is attracted to the anode where it combines with carbon plus any impurities, such as sulfur, which may be present. The anode is consumed by this process and must be replaced periodically.

ANTHRACITE COAL: A hard, black, lustrous coal containing a high percentage of fixed carbon and a low percentage of volatile matter. Commonly referred to as "hard coal," it is mined in the United States, mainly in eastern Pennsylvania, as well as in small quantities in other states.

AREA SOURCE: Any small residential, governmental, institutional, commercial, or industrial fuel combustion operations, as well as on-site waste disposal and transportation sources (see point source).

ASH: The noncombustible solid matter in fuel.

ASH-FREE BASIS: The method of reporting fuel analysis whereby ash is deducted and other constituents are recalculated to total 100 percent.

ASME: The American Society of Mechanical Engineers.

ASPIRATING BURNER: A burner in which the fuel in a gaseous or finely divided form is burned in suspension. The air of combustion is supplied by drawing it through one or more openings by the lower static pressure created by the velocity of the fuel stream.

ASTM: The American Society for Testing and Materials.

ATOMIZER: A device by means of which a liquid is reduced to a very fine spray.

ATMOSPERIC PRESSURE: The pressure due to the weight of the atmosphere. Normal atmospheric pressure at sea level is approximately 14.7 p.s.i. or 29.92 inches of mercury.

AVAILABLE HEAT: The quantity of useful heat per unit of fuel available from complete combustion after deducting dry flue gas and water vapor losses.

B

BAGASSE: Sugar cane from which the juice has been essentially extracted.

BAG FILTER: A device containing one or more cloth bags for recovering particles from the dust-laden gas which is blown through it.

BAGHOUSE: Structures containing several bag filters (see bag filters).

BAG-TYPE COLLECTOR: A filter wherein the cloth filtering medium is made in the form of cylindrical bags.

BANKING: Burning solid fuels on a grate at rates sufficient to maintain ignition only.

BARK BOILER: A combustion unit designed to burn mainly bark and wood residues, used to produce steam for process or electrical energy.

BAROMETRIC CONDENSER: An inexpensive direct contact condenser used when condensate recovery is not a factor. In this type of condenser, steam rises into a rain of cooling water, and both condensed steam and water flow out of the bottom of the condenser, maintaining a partial vacuum in the condenser.

BASE STOCK: A sheet, usually produced from unbleached kraft pulp, formed into linerboard on a fourdrinier machine.

BATCH FED INCINERATOR: An incinerator that is charged with refuse periodically, the charge being allowed to burn down or burn out before another charge is added.

BINDER: See core binder.

BITUMINOUS COAL: Soft coal, dark brown to black in color, having a relatively high proportion of gaseous constituents and usually burning with a smoky luminous flame.

BLACK LIQUOR: Spent chemical solution which is formed during the cooking of wood pulp in the digester. The black liquor is burned as a fuel in the recovery furnace.

BLAST FURNACE: A shaft furnace in which solid fuel is burned with an air blast to smelt ore.

BLEEDER: A bypass or relief valve used to relieve excess pressure.

BLISTER COPPER: An impure intermediate product in the refining of copper, produced by blowing copper bearing material in a converter; the name is derived from the large blisters on the cast surface that result from the liberation of SO_2 and other gases.

BLOWBACK: The difference between the pressure at which a safety valve opens and at which it closes, usually about three percent of the pressure at which the valve opens.

BLOWDOWN: Hydrocarbons purged during refinery shutdowns and startups which are manifolded for recovery, safe venting, or flaring.

BOILER: A closed pressure vessel in which the liquid, usually water, is vaporized by the application of heat.

BOILER HORSEPOWER: A unit of rate of water evaporation. One boiler horsepower equals the evaporation of 34.5 lb. of water per hour from a temperature of 212°F into dry saturated steam at the same temperature (equivalent to 33,472 Btu per hour).

BRASSESS: Copper-based alloy of 60-65% copper. Alloying material is usually zinc.

BREAKER: In anthracite mining, the structure in which the coal is broken, sized, and cleaned for market. Also known as a coal breaker. A machine used for the primary reduction of coal, ore, or rock.

BREECHING: A sheet-iron or sheet-metal casing at the end of boilers for conveying the smoke from the flues to the smokestack.

BRIGHTENING: The process of producing bright stock (see bright stock).

BRIGHT STOCK: Refined high viscosity lubricating oils usually made from residual stocks by suitable treatment, such as a combination of acid treatment or solvent extraction with dewaxing or clay finishing.

BRITISH THERMAL UNIT (Btu): The mean British thermal unit is 1/180 of the heat required to raise the temperature of one pound of water from 32°F to 212°F at a constant atmospheric pressure. It is about equal to the quantity of heat required to raise one pound of water 1°F. A Btu is essentially 252 calories.

BRONZES: Copper based alloy of 85-90% copper. Alloying material is usually tin.

BUNKER C OIL: Residual fuel oil of high viscosity commonly used in marine and stationary power plants (No. 6 fuel oil).

BURNER: A device for the introduction of fuel and air into a furnace at the desired velocities, turbulence, and concentration to establish and maintain proper ignition and combustion of the fuel.

BUSS (BUSBAR): A heavy metal conductor, usually copper, for high amperage electricity.

BUSTLE PIPE: In steel making, a metal tube of large diameter which surrounds a blast furnace at a level a little above the tuyeres; it is lined with refractory material and distributes the hot air from the blast stoves to the pipes (goosenecks) which carry the air to the tuyeres.

C

CALCINE: Ore or concentrate which has been treated by calcination or roasting and which is ready for smelting.

CALCINING: Roasting of ore in an oxidizing atmosphere usually to expel sulfur or carbon dioxide. If sulfur removal is carried to practical completion, the operation is termed "sweet roasting"; if all CO_2 is removed, the operation is termed "dead roasting."

CALORIE: The mean calorie is 1/1000 of the heat required to raise the temperature of one gram of water from 0°C to 100°C at a constant atmospheric pressure. It is about equal to the quantity of heat required to raise one gram of water 1°C.

CARBONIZATION: The process of converting coal to carbon in the absence of air by using intense heat to remove volative ingredients.

CARBON LOSS: The loss representing the unliberated thermal energy caused by failure to oxidize some of the carbon in the fuel.

CARCINOGENIC: Producing or tending to produce cancer.

CARRYOVER: The chemical solids and liquid entrained in the steam from a boiler or effluent from a fractionating column, absorber, or reaction vessel.

CATALYST: A substance capable of changing the rate of a reaction without itself undergoing any net change.

CATALYTIC CRACKING: The conversion of high boiling hydrocarbons into lower boiling substances by means of a catalyst which may be used in a fixed bed, moving bed, or fluid bed. Natural or synthetic catalysts are employed in bead, pellet, or powder form. Feedstocks may range from naphtha cuts to reduced crude oils.

CATHODE: In aluminum production, the negatively charged terminal of the reduction cell to which the aluminum migrates. The terminal consists of the carbon lining that makes up the bottom of the cell.

CAVING: In metal mining, caving implies the dropping of the over-burden as part of the system of mining.

CHARGING: Feeding raw material into an apparatus, for example, into a furnace, for treatment or conversion.

CHLOROSIS: A diseased condition in green plants marked by yellowing or blanching of the leaves.

CINDERS: Particles not ordinarily considered as fly ash or dust because of their greater size; these particles consist essentially of fused ash and/or unburned matter.

CLEANING FIRES: The act of removing ashes from the fuel bed or furnace.

CLINKERS, CEMENT: The glassy, stony, lump-like product of fusing together clay and limestone as the first stage in the manufacture of portland cement.

COAL DESULFURIZATION: See desulfurization.

COAL GAS: Gas formed by the destructive distillation of coal.

COAL TAR: A black viscous liquid formed as a by-product from the distillation of coal.

COKE: Bituminous coal from which the volatile constituents have been driven off by heat so that the fixed carbon and the ash are fused together.

COKE BREEZE: Fine coke particles leaving the coke quencher with the quenched coke by conveyor. The particles are very fine and may be blown away.

COKE, PETROLEUM: The solid carbonaceous residue remaining as the final product of the condensation processes in cracking. It consists of highly polycyclic aromatic hydrocarbons very poor in hydrogen. It is used extensively in metallurgical processes. Calcination of petroleum coke can yield almost pure carbon or artificial graphite suitable for production of electrodes, motor brushes, dry cells, etc.

COKING: 1. Carbonization of coal by destructive distillation. 2. In petroleum refining: any cracking process in which the time of cracking is so long that coke is produced as the bottom product; thermal cracking for conversion of heavy, low-grade oils into lighter products and a residue of coke; or the undesirable building up of coke or carbon deposits on refinery equipment.

COLLECTION EFFICIENCY: The ratio of the weight of pollutant collected to the total weight of pollutant entering the collector.

COLLOID: 1. A substance composed of extremely small particles, ranging from 0.005 micro-meters to 0.2 micro-meters, which when mixed with a liquid will not settle, but will remain suspended. The colloidal suspension thus formed has properties that are quite different from the simple solution of the two substances. 2. In fuel burning, a finely divided organic substance which tends to inhibit the formation of dense scale and results in the deposition of sludge, or causes it to remain in suspension, so that it may be blown from the boiler.

COLLOIDAL FUEL: Mixture of fuel oil and powdered solid fuel.

COMBINATION BOILER: A combustion unit used to produce steam for process or electrical energy which is designed to burn bark and at least one other fuel.

COMBUSTION CONTAMINANTS: Particulate matter discharged into the atmosphere from the burning of any kind of material containing carbon.

COMBUSTION TOWER: Refractory graphite-lined or water-jacketed stainless steel tower in which phosphorus is burned to phosphorus pentoxide.

CONDENSED FUMES: Minute solid particles generated by the condensation of vapors from solid matter after volatilization from the molten state, or generated by sublimation, distillation, calcination, or chemical reaction when these processes create airborne particles.

CONDENSER BOILER: A boiler in which steam is generated by the condensation of a vapor.

CONTACT CONDENSER: A condenser in which coolant, vapors, and condensate are mixed.

CONTINUOUS-FEED INCINERATOR: An incinerator into which refuse is charged in a nearly continuous manner in order to maintain a steady rate of burning.

CONTROL STRATEGY: A combination of measures designed to achieve the aggregate reduction of emissions necessary for attainment and maintenance of a national ambient air quality standard.

CONVECTION: The transmission of heat by circulation of a liquid or a gas. Convection may be natural or forced.

CONVERTER: 1. A furnace in which air is blown through a bath of molten metal or matte, oxidizing the impurities and maintaining the temperature through the heat produced by the oxidation reaction. 2. In nitric acid production, the chamber in which ammonia is converted to nitric oxide and water by reacting it with air over a platinum-rhodium catalyst.

CONVERTING: The process of removing impurities from molten metal or metallic compounds by blowing air through the liquid. The impurities are changed either to gaseous compounds, which are removed by volatilization, or to liquids or solids which are removed as slags.

CORE: The central part of a sand mold as used in foundries. The device placed in a mold to make a cavity in a casting.

CORE BINDER: Organic material added to foundry sand to aid in formation of a strong core for casting. Flour, linseed oil, starch, and resins are among materials used.

CRACKING: Chemical reaction by which large oil molecules are decomposed into smaller, lower-boiling molecules. At the same time, certain of these molecules, which are reactive, combine with one another to give even larger molecules than those in the original stock. The more stable molecules leave the system as cracked gasoline, but the reactive ones polymerize, forming tar and even coke. Cracking may be in either the liquid or vapor phase. When a catalyst is used to bring about the desired chemical reaction, this is called "catalytic cracking"; otherwise, it is assumed to be "thermal cracking" (see catalytic cracking).

CRACKLINGS: The crisp residue left after the fat has been separated from the fibrous tissue in rendering lard or frying or roasting the skin of pork, turkey, duck, or goose.

CRUSHER: A machine for crushing rock or other materials. Among the various types of crushers are the ball mill, gyratory crusher, Hadsel mill, hammer mill, jaw crusher, rod mill, rolls, and stamp mill.

CRYOLITE: Sodium aluminum fluoride (Na_3AlF_6) used as an electrolyte in smelting of alumina to provide aluminum.

CULM: The fine refuse from anthracite coal production.

CUPOLA: A vertical shaft furnace used for melting metals, especially grey iron, by having the charge come in contact with the hot fuel, usually metallurgical coke. Metal, coke, and flux are charged from the top of the furnace onto a bed of hot coke through which air is blown.

CURTAIN WALL: A partition wall between chambers in an incinerator under which combustion gases pass.

CYCLONE: A structure without moving parts in which the velocity of an inlet gas stream is transformed into a confined vortex from which centrifugal forces tend to drive the suspended particles to the wall of the cyclone body. The particles then slide down the cyclone wall and are collected at the bottom.

CYCLONE SCRUBBERS: Devices ranging from simple dry cyclones with spray nozzles to multistage devices. All feature a tangential inlet to a cylindrical body.

CYCLONIC SPRAY TOWER: Liquid scrubbing apparatus where sprays are introduced countercurrent to gases for removal of contaminants.

D

DEHYDROGENATION: The removal of hydrogen from a chemical compound; for example, the removal of two hydrogen atoms from butane to make butylene, and the further removal of hydrogen to make butadiene.

DEMISTER (COLLECTOR): 1. A mechanical device used to eliminate finely divided liquid particles from process streams by impaction and agglomeration. 2. Apparatus made of wire mesh or glass fiber and used to eliminate acid mist as in the manufacture of sulfuric acid.

DESTRUCTIVE DISTILLATION: 1. A process of distillation in which an organic compound or mixture is heated to a temperature high enough to cause decomposition. 2. The heating of organic matter when air is not present, resulting in the evolution of volatile matter and leaving char consisting of fixed carbon and ash.

DESULFURIZATION: 1. In coal processing, the removal of sulfur from the coal, often by mechanical cleaning processes. 2. In petroleum refining, removing sulfur or sulfur compounds from a charge stock (oil that is to be treated in a particular unit).

DIFFUSION: The spreading or scattering of a gaseous or liquid material. 1. Eddy diffusion: diffusion caused by turbulent activity in a fluid system. 2. Molecular diffusion: a process of spontaneous intermixing of different substances, attributed to molecular motion and tending to produce uniformity of concentration.

DIRECT-FIRED BOILER: Commonly used to denote a boiler and furnace fired by pulverized coal.

DISPERSION: The dilution of a pollutant by diffusion, or turbulent action, etc. Technically, a two-phase system of two substances, one of which (the dispersed phase) is uniformly distributed in a finely divided state through the second substance (the dispersion medium). Either phase may be a gas, liquid, or solid.

DISTILLATE: The product of distillation obtained by condensing the vapors from a still.

DISTILLATE FUELS: Liquid fuels distilled usually from crude petroleum, except residuals such as No. 5 and No. 6 fuel oil.

DISTILLATE OILS: The lighter oils produced by distilling crude oil.

DISTILLATION: The process of heating a substance to the temperature at which it is converted to a vapor, then cooling the vapor, and thus restoring it to the liquid state.

DOCTOR TREATMENT: Treatment of gasoline with sodium-plumbite solution and sulfur to improve its odor.

DOPES FOR GASOLINES: Materials added in small amounts to gasoline to increase the octane number and thus help to prevent knocking.

DOUBLE DECOMPOSITION: A chemical reaction between two compounds in which part of the first compound becomes united with the remainder of the second, as: AB + CD = AD + BC.

DRAFT: A gas flow resulting from the pressure difference between the incinerator, or any component part, and the atmoshpere, which moves the products of combustion from the incinerator to the atmosphere. 1. Natural draft: the negative pressure created by the difference in density between the hot flue gases and the atmosphere. 2. Induced draft: the negative pressure created by the vacuum action of a fan or blower located between the incinerator and the stack. 3. Forced draft: the positive pressure created by the action of a fan or blower, which supplies the primary or secondary air.

DROP ARCH: A refractory construction or baffle which serves to deflect gases in a downward direction.

DROSS: 1. Impurity formed in melted metal. A zinc-and-iron alloy forming in a bath of molten zinc, in galvanizing iron. 2. The scum that forms on the surface of molten metals usually due to oxidation, but occasionally due to the rising of impurities to the surface.

DRUM, FLASH (OR FLASH TOWER): A drum or tower into which the heated outlet products of a preheater or exchanger system are conducted, often with some release in pressure. The purpose of the drum is to allow vaporization and separation of the volatile portions for fractionation elsewhere.

DRY BOTTOM FURNACE: A furnace designed to burn pulverized coal at temperatures low enough to prevent the ash from fusing or slagging.

DUST: Generally particles from 1 to 100 micro-meters in size that become airborne by natural or mechanical means. These particles do not diffuse but will settle under the influence of gravity (see also particle).

DUST COLLECTING FAN: A centrifugal fan which concentrates dust and skims it into a cyclone or hopper.

DUSTLESS LOADING: The amount of dust in a gas, usually expressed in grains per cubic foot or in pounds per thousand pounds of gas (see also grain loading).

E

ECONOMIZER: A heat recovery device designed to transfer heat from the products of combustion to a fluid, usually feedwater for a steam boiler. The water flows through a bank of tubes placed across the flue gases and is heated by these gases prior to entering the boiler.

EFFICIENCY: The ratio of output to input. The efficiency of a steam generating unit is the ratio of the heat absorbed by the water or steam to the heat in the fuel fired, expressed in percent.

EFFLUENT: Any waste material (solid, liquid, gas) emitted by a process.

EFFLUENT WATER SEPARATOR: A container designed to separate volatile organic compounds from waste water prior to discharge or reuse.

ELECTROLYSIS: 1. Chemical change resulting from the passage of an electric current through an electrolyte. 2. Transfer or transport of matter through a medium by means of conducting ions (positively or negatively charged particles). The medium may consist of fused salts or conducting solutions which permit free movement of ions toward the countercharged electrodes immersed in the system

ELECTROSTATIC PRECIPITATOR: Devices that separate particles from a gas stream by passing the carrier gas between two electrodes across which a unidirectional, high-voltage electrical charge is placed. The particles pass through this field, become charged and migrate to the oppositely charged electrode. Single-stage precipitators are those in which gas ionization and particulate collection are combined into a single step. In the two-stage unit, ionization is achieved by one element of the unit and the collection by the other. Electrostatic precipitators are highly efficient collectors for minute particles.

ELUTRIATOR: A vertical tube through which a gas or fluid passes upward at a specific velocity while a solid mixture whose separation is desired is fed into the top of the column. The large particles which settle at a velocity higher than that of the rising fluid are collected at the bottom of the column, and the smaller particles are carried out of the top of the column with the fluid.

EMISSION: The total amount of a solid, liquid, or gaseous pollutant emitted into the atmosphere from a given source in a given time, and indicated in grams per cubic meter of gas, pounds per hour, or other quantitative measurement.

ENDOTHERMIC REACTION: A reaction which requires the addition of heat for its continuation.

ENTRAINMENT: The process of particulates or other materials being carried along by a gas stream.

EVAPORATOR: Usually a vessel which receives the hot discharge from a heating coil and, by a reduction in pressure, flashes off overhead the light products and allows the heavy residue to collect in the bottom (see flash tower).

EXCESS AIR: Air supplied for combustion in excess of that theoretically required for complete combustion, usually expressed as a percentage of theoretical air, such as "130 percent excess air."

EXOTHERMIC REACTION: A reaction which produces heat.

F

FABRIC FILTER: See bag filter.

FIXED CARBON: That part of the carbon which remains when coal is heated in a closed vessel until the volatile matter is driven off. It is the nonvolatile matter minus the ash.

FEEDSTOCK: Starting material used in a process. This may be raw material or an intermediate product that will undergo additional processing.

FLOATING ROOF: A special tank roof which floats upon the oil in a storage tank.

FLUE: Any duct, passage, or conduit through which the products of combustion are carried to a stack or chimney (see also breeching).

FLUE GAS: The gaseous products of combustion passing from the furnace into the stack.

FLUIDIZED ROASTING: Oxidation of finely ground pyritic minerals by means of upward currents of air, blown through a reaction vessel (fluid bed roaster) with sufficient force to cause the bed of material to expand (boil). Reaction between mineral and air is maintained at a desired exothermic level by control of oxygen entry, by admission of cooling water, or by addition of fuel.

FLUOROSIS: A chronic poisoning resulting from the presence of 0.9 milligrams or more per liter of fluorine in drinking water. Teeth become brittle and opaque white with a mottled enamel.

FLUOROSPAR: A natural calcium fluoride (CaF_2) used as a flux in open hearth steel furnaces and in gold, silver, copper, and lead smelting.

FLUX: 1. In chemistry and metallurgy, a substance that promotes the fusing of minerals or metals or prevents the formation of oxides. 2. A substance added to a solid to increase its fusibility. 3. A substance to reduce melting temperature. 4. Any chemical or rock added to an ore to assist in its reduction by heat, such as limestone with iron ore in a blast furnace.

FLY ASH: In incineration, suspended incombustible particles, charred paper, dust, soot, or other partially incinerated matter, carried in the gaseous products of combustion.

FOOD-GRADE ACID: Phosphoric acid that has been treated for removal of heavy metals and is suitable for use in food products.

FORCED DRAFT: See draft.

FRACTIONAL DISTILLATION: The separation of the components of a liquid mixture by vaporizing and collecting the fractions which condense in different temperature ranges.

FUEL: Any form of combustible matter--solid, liquid, vapor, or gas, excluding combustible refuse.

FUEL-BURNING EQUIPMENT: Any furnace, boiler, apparatus, stack, and all appurtenances thereto, used in the process of burning fuel for the primary purpose of producing heat or power by indirect heat transfer.

FUGITIVE DUST: Solid airborne particulate matter emitted from any source other than a flue or stack.

FUME: Fine solid particles predominately less than 1 micro-meter in diameter suspended in a gas. Usually formed from high-temperature volatilization of metals, or by chemical reaction.

FUMIGATION: Fumigation is an atmospheric phenomenon in which pollution, which has been retained by an inversion layer near its level of emission, is brought rapidly to ground level when the inversion breaks up. High concentrations of pollutant can thus be produced at ground level.

FUMING NITRIC ACID: A mixture of 98 percent nitric acid and an equilibrium mixture of nitrogen tetroxide (N_2O_4) and nitrogen dioxide (NO_2).

FURNACE OIL: A distillate fuel primarily intended for domestic heating use. No. 1 commercial standard grade is intended for "vaporizing" burners requiring a volatile fuel, whereas No. 2 and No. 3 commercial standard grades are less volatile, and are thus usable in the "atomizing" type of burners.

G

GAGE PRESSURE: The pressure above atmospheric pressure, expressed as pounds per square inch, gage (psig).

GOB PILES: Large piles of low-combustible refuse from coal mine preparation plants. Fires may develop in these waste material piles by liberation of heat through slow oxidation, until ignition temperature is reached (see also culm).

GRAIN LOADING: Concentration of particulates in exhaust gas, expressed as grains per standard cubic foot (7000 grains = 1 pound) (see also dust loading).

GRAVITATIONAL SETTLING: Removal of material from the atmosphere due to the action of gravity.

GREEN COKE: Coke that has not been fully cooked. Green coke produces excessive emissions when pushed from a coke oven.

GREEN FEED (CALCINED FEED): Not fully processed or treated feed.

GROUT (GROUTING): A pumpable slurry of portland cement or a mixture of portland cement and fine sand commonly forced into a borehole to seal crevices in a rock to prevent ground water from seeping or flowing into an excavation or for extinguishing underground fires.

H

HEAT ISLAND EFFECTS: Meteorological characteristics of an urban area or large industrial complex which differentiates it from its surroundings. Generally, the urban area has (1) higher temperatures, (2) a less stable noctournal lapse rate immediately above the surface, (3) lower relative humidities, (4) greater cloudiness, (5) more frequent fogs, (6) less incoming radiation, (7) lower wind speeds, and (8) greater precipitation.

HEAT RELEASE RATE: The amount of heat liberated during the process of combustion and expressed in Btu per hour per cubic foot of internal furnace volume in which the combustion takes place.

HOG FUEL BOILER: See bark boiler.

HOT BLAST MAIN: A duct lined with refractory material, through which hot air passes from a hot blast stove to the bustle pipe of a blast furnace.

HOT WELL: A reservoir for receiving warm condensed steam drawn from a condenser.

HYDRATOR-ABSORBER: A single or double tower in which phosphorus pentoxide is hydrated to phosphoric acid and the resulting acid mist is absorbed.

HYDRAULIC FLY ASH HANDLING: A system using water-filled pipes or troughs in which fly ash is conveyed by means of gravity, water jets, or centrifugal pumps.

HYDROCARBONS: Organic compounds which consist solely of carbon and hydrogen and occur in petroleum, natural gas and coal.

HYDROCRACKING: A low-temperature catalytic method of converting crude oil, residual oil, petroleum tar, and asphalt to high-octane gasoline, jet fuel, and/or high-grade fuel oil. The process combines cracking, hydrogenation, and isomerization.

HYDRODESULFURIZATION: A desulfurization process in which the oil is heated with hydrogen.

HYDROGENATION: The chemical addition of hydrogen to a material at high pressure in the presence of a catalyst.

HYDROMETALLURGY: The treatment of ores, concentrates, and other metal-bearing materials by wet processes, usually involving the solution of some component, and its subsequent recovery from the solution.

HYDROTREATING: A treating process using hydrogen for the desulfurization of cracked distillates.

I

IMPINGEMENT: In air sampling, impingement refers to a process for the collection of particulate matter in which the gas being sampled is directed forcibly against a surface. 1. Dry impingement: the process of impingement in the gas stream where particulate matter is retained upon the surface against which the stream is directed. The collecting surface may be treated with a film of adhesive. 2. Wet impingement: the process of impingement in a liquid which retains the particulate matter.

IMPINGEMENT SEPARATORS: Devices using the principle that when a gas stream carrying particulate matter impinges on a body, the gas is deflected around the body, while the particles, because of their greater inertia, tend to strike the body and be collected on its surface. The bodies may be in the form of plates, cylinders, ribbons, or spheres.

INCINERATION: The process of burning solid, semi-solid, or gaseous combustible waste.

INCINERATOR: An apparatus designed to burn solid, semi-solid, or gaseous waste leaving little or no combustible material (see multiple chamber incinerator).

INERTIAL SEPARATOR: The most widely used device for collecting medium and coarse sized particles. Inertial separators operate by the principle of imparting centrifugal force to the particle to be removed from the carrier gas stream.

INTERRUPTIBLE GAS: Gas sold whereby the seller may curtail or stop delivery, generally at his option. The gas customer under these conditions is expected to have standby equipment capable of taking over 100% of his needs by an alternate fuel.

INVERSION: A stratum in the atmosphere through which the temperature increases with height. The layer is thermally stable and vertical motion within the layer is suppressed.

INVERSION BASE: The lowest height in the atmosphere at which the temperature ceases to decrease with height.

ISOMERIZATION: A reaction which alters the fundamental arrangement of the atoms in a molecule without adding or removing anything from the original material. In the petroleum industry, straight-chain hydrocarbons are converted catalytically to branched-chain hydrocarbons of substantially higher octane number by isomerization.

J

JIG: A device which separates coal from foreign matter by means of their difference in specific gravity in a water medium. The water pulsates up and down causing the heavy material to work to the bottom.

K

KETTLE: 1. An open-top vessel used in carrying out metallurgical operations on low-melting-point metals; for example, in drossing and desilverizing lead. 2. An open or (usually) closed vessel for preparing paints, varnishes, and resins.

KILN: A furnace in which the heating operations do not involve fusion. Kilns are most frequently used for calcining, and free access of air is permitted. The raw materials may be heated by the combustion of solid fuel with which they are mixed, but more usually they are heated by gas or the waste heat from other furnaces.

KILN GAS: Hot effluent gases from a kiln. Unless controlled, these gases can be the largest source of particulates in a plant.

KNOCKOUT DRUM: A drum or vessel constructed with baffles through which a mixture of gas and liquid is passed to disengage one from the other. As the mixture comes in contact with the baffles, the impact frees the gases and allows them to pass overhead; the heavier substance falls to the bottom of the drum.

L

LAPSE RATE: The decrease of temperature with altitude.

LAUNDER: A trough, channel, or gutter usually of wood, by which water is conveyed. Specifically, in mining, a chute or trough for conveying powered ore, or for carrying water to or from the crushing apparatus.

LEACHING: Extracting a soluble metallic compound from an ore by selectively dissolving it in a suitable solvent, such as water, sulfuric acid, hydrochloric acid, etc.

LIGNITE COAL (BROWN COAL): A brownish-black variety of coal, usually high in moisture and low in Btu's. Lignite is one of the earlier stages in the formation of bituminous coal.

M

MANIFOLD: A pipe or header for collecting a fluid or gas from, or distributing a fluid or gas to, a number of pipes or tubes.

MANUFACTURED GAS: Fuel gas manufactured from coal, oil, etc., as differentiated from natural gas.

MATERIAL BALANCE: An accounting of the weights of material entering and leaving a process.

MATTE: A metallic sulfide mixture formed in smelting sulfide ores of copper, lead, and nickel.

MECHANICAL, CENTRIFUGAL SEPARATORS: A device for separating particulates. A rotating fan blade exerts a large centrifugal force on the particulates, ejecting them from the tips of the blades to a skimmer bypass leading into a dust hopper.

MECHANICAL SCRUBBER: A scrubber in which the water spray is generated by a rotating element or disk (see also scrubber).

MECHANICAL TURBULENCE: In meteorology, the induced eddy structure of the atmosphere due to the roughness of the surface over which the air is passing. The height and spacing of the elements causing the roughness will affect the turbulence.

MERCAPTANS: Organic compounds having the general formula R-SH (where R represents any hydrocarbon radical) which are analogous to the alcohols and phenols but which contain sulfur in place of oxygen. The simpler mercaptans have strong, repulsive odors.

MESH: The number of holes per linear unit in a sieve or gauze, or the space between the wires of the sieve expressed in inches or millimeters.

METRIC TON: 2204.6 pounds or 1000 kilograms.

MIST: A suspension of any finely divided liquid [illegible] a gas.

MODIFIED COAL: Coal of a stoker size containing a controlled percentage of fines.

MULTICYCLONE (ALSO MULTIPLE CYCLONE OR MULTICLONE): A dust collector consisting of a number of cyclones, operating in parallel, through which the volume and velocity of gas can be regulated by means of dampers to maintain dust-collector efficiency over the load range.

MULTIPLE-CHAMBER INCINERATOR: Any incinerator consisting of a primary combustion chamber, mixing chamber, and secondary combustion chamber in series. The chambers are separated by refractory walls, and interconnected by gas passage ports.

MULTIPLE-HEARTH TYPE ROASTER: See roasting furnace.

MUNICIPAL INCINERATOR: An incinerator owned or operated by government or by a person who provides incinerator service to government or others; a device designed for and used to burn waste materials of any and all types.

N

NATURAL GAS: Gaseous forms of petroleum occurring in nature and used directly as a fuel. Natural gas consists of mixtures of hydrocarbon gases and vapors, the more important of which are methane, ethane, propane, and butane.

NET TON: 2000 pounds (sometimes known as a "short ton").

NITROGEN OXIDES: A general term pertaining to a mixture of nitric oxide (NO) and nitrogen dioxide (NO_2).

O

ODORANT: A gaseous nuisance that is offensive or objectionable to the smell.

ODOR INTENSITY: The numerical or verbal indication of the strength of an odor.

ODOR PERVASIVENESS: The ability of an odor to diffuse into a large volume of air and still continue to possess a detectable intensity. A pervasive odor is one whose odor intensity changes very little on dilution.

ODOR QUALITY: A verbal description of an odor. The quality may be described in terms of such familiar odorants as coffee, onions, lemons, or by associating an unfamiliar odor with a familiar odor.

ODOR THRESHOLD: The lowest concentration of an odor in air that can be detected by a human.

ODOR UNITS: That quantity of odor necessary to contaminate one cubic foot of air to threshold or barely perceptible level. The number of odor units is equal to the volumes (scf) of air necessary to dilute the concentration of odorant in one volume (scf) of air to the threshold concentration.

OIL BURNER: Any device for the introduction of vaporized or atomized fuel oil into a furnace.

OIL-EFFLUENT WATER SEPARATOR: Any tank, box, sump, or other container in which any petroleum product entrained in water is physically separated and removed prior to out-fall, drainage, or recovery of the water.

OITICICA (OIL): A drying oil obtained from the kernels of the fruit of the oiticica tree that is similar to tung oil in many properties and is used chiefly in varnishes, paints, and printing inks.

OLEORESIN: A varnish or paint vehicle, made of plant oils and resins, usually cooked.

OLEUM (FUMING SULFURIC ACID): A heavy, oily, strongly corrosive liquid that consists of a solution of sulfur trioxide in anhydrous sulfuric acid. It fumes in moist air and reacts violently with water.

ONSTREAM TIME: The length of time a unit is in actual production.

OPACITY: The degree to which emissions reduce the transmission of light and obscure the view of a distant object.

OPEN BURNING: The burning of any matter in such a manner that the products of combustion are emitted directly into the ambient air without passing through a stack, duct, or chimney.

OPEN HEARTH FURNACE: Reverberatory furnace, containing a basin-shaped hearth, for melting and refining suitable types of pig iron, iron ore, and scrap for steel production.

ORE AND LIME BOIL: Reactions which occur in an open hearth furnace when carbon monoxide is produced by the oxidation of carbon. Ore boil is a violent agitation of the metal as it escapes during this process; lime boil occurs when the limestone decomposes and the carbon dioxide gas escapes. The second reaction begins before the first is completed.

ORGANIC SULFUR: The difference between the total sulfur in coal and the sum of the pyritic sulfur and sulfate sulfur.

ORGANOLEPTIC: Affecting or making an impression upon one or more of the sense organs.

ORIFICE SCRUBBERS: Devices for the removal of particulates from gas streams in which the flow of air through a restricted passage partially filled with water causes the dispersion of the water and consequent wetting and collection of the particulates.

ORSAT: An apparatus used for analyzing flue gases volumetrically.

OVERBURDEN: Material of any nature, consolidated or unconsolidated, that overlies a deposit of useful material, ores, or coal, especially those deposits that are mined from the surface by open cuts.

OVERFIRE: Air for combustion admitted into the furnace at a point above the fuel bed.

OXIDATION: The act or process of combining oxygen with a substance, with or without the production of a flame.

OXYGEN LANCING: In steel making, a procedure in which oxygen is injected into the bath of molten metal through a water cooled lance. The oxygen oxidizes carbon, silicon, manganese, and some iron in exothermic reactions. The procedure materially shortens the time needed to tap the furnace.

P

PACKED COLUMN (PACKED SCRUBBER OR PACKED TOWER): A vertical column used for distillation, absorption, and extraction, containing packing; e.g., Raschig rings, Berl saddles, or crushed rock, which provide a large contacting surface area between phases. Normally, gas flow is countercurrent to liquid flow.

PAN: Peroxyacyl nitrates. Secondary pollutants formed in photochemical oxidation and major eye irritants of photochemical smog.

PARTICLE CONCENTRATION: Concentration expressed in terms of number of particles per unit volume of air or other gas.

PARTICULATE MATTER: Any dispersed matter, solid or liquid, in which the individual aggregates are larger than single small molecules (0.0002 micrometers) but smaller than 500 micro-meters.

PERCOLATOR: A device used in rendering plants for the separation of dry proteinaceous crackling from the clear moisture-free tallow. They are generally perforated pans which allow the tallow to drain away from the cracklings.

PERFORMANCE TEST: Measurements of emissions used for the purpose of determining compliance with a standard of performance.

PETROCHEMICAL INDUSTRY: A branch of the petroleum industry in which refined crude oil is manufactured into various chemicals.

PETROLEUM COKE: See coke, petroleum.

PHOTOCHEMICAL REACTION: A chemical reaction which involves either the absorption or emission of radiation in the form of light energy.

PLUME: The path taken by the continuous discharges of products from a chimney or stack. The shape of the path and the concentration distribution of gas plumes is dependent on turbulence of the atmosphere.

POINT SOURCE: Any stationary emitting point or plant/facility whose summation of emitting points totals 100 tons (or some other fixed amount) per year of any pollutant in a given region.

POLYCYCLIC MOLECULE: A molecule containing two or more fused rings (as in anthracine).

POLYMERIZATION: 1. A reaction combining two or more molecules to form a single molecule having the same elements in the same proportions as in the original molecules. 2. The union of light olefins to form hydrocarbons of higher molecular weight. The process may be thermal or catalytic.

POLYNUCLEAR AROMATIC HYDROCARBONS: Compounds consisting of two or more aromatic rings which share a pair of carbon atoms. The simplest and most important is naphthalene ($C_{10}H_8$; also polycyclic).

PRECLEANERS: Collectors of limited efficiency used ahead of the final cleaner. If the gas contains an appreciable amount of hard, coarse particles, a precleaner can materially reduce erosive wear of the more efficient final collector.

PRECURSORS: Gaseous air pollutants which react with other substances in the atmosphere to produce different pollutants; e.g., photochemical reactions of NO and NO_2 with the oxygen of the air which produce ozone.

PRILLING: A combination spray drying and crystallization technique used in the production of ammonium nitrate. A hot ammonium nitrate solution is sprayed in the top of a tower, and air is blown in at the bottom. The liquid is converted into spherical pellets.

PRIMARY AIR: In incineration, air which is introduced with the refuse into the primary chamber.

PRIMARY EMISSION: Pollutants emitted directly into the air from identifiable sources.

PRIMARY STANDARD: The national primary ambient air quality standard which defines levels of air quality which are necessary to protect public health.

PROCESS WEIGHT: The total weight of all materials introduced into a source operation, including solid fuels, but excluding liquids and gases used solely as fuels, and excluding air introduced for purposes of combustion.

PUG MILL: A machine for mixing water and clay which consists of a long horizontal barrel within which is a long longitudinal shaft fitted with knives which slice through the clay, mixing it with water which is added by sprayers from the top. The knives are canted to give some screw action, forcing the clay along the barrel and out one end.

PUMP, RECIPROCATING: A positive-displacement type of pump consisting of a plunger or a piston moving back and forth within a cylinder. With each stroke of the plunger or piston, a definite volume of liquid is pushed out through the discharge valves.

PYRITIC SULFUR: Sulfur combined with iron, found in coal.

PYROLYSIS: Chemical change brought about by the action of heat upon a substance.

PYROMETER: An instrument for measuring temperatures beyond the range of thermometers.

R

RECOVERY BOILER: In wood pulping, a combustion unit designed to recover the spent chemicals from the cooking liquor and to produce steam for pulping and recovery operations.

REDUCTION: 1. The addition of hydrogen or the abstraction of oxygen from a substance. 2. The extraction of any metal from its ore.

REFINERY GAS: Any form or mixture of still gas gathered in a refinery from the various stills.

REFINING: In metallurgy, the removal of impurities necessary to produce an ingot or alloy of desired specification. In petroleum, the process of separating, combining, or rearranging petroleum oil constituents to produce salable products.

REFORMING: The thermal or catalytic conversion of naphtha into more volatile products of higher octane number. It represents the total effect of numerous reactions, such as cracking, polymerization, dehydrogenation, and isomerization, taking place simultaneously.

REFRACTORY: A ceramic material of a very high melting point with properties that make it suitable for such uses as furnace and kiln linings.

RERUN OIL: Oil which has been redistilled.

RESIDUAL: Heavy oil left in the still after gasoline and other distillates have been distilled off, or residue from the crude oil after distilling off all but the heaviest components.

RESISTIVITY: The property of a body whereby it opposes and limits the passage of electricity through it. Resistivity of dust is an important factor in the performance of electrostatic precipitators. If the resistivity of the collected dust is higher than about 2×10^{10} ohm-cm, excessive arcing or reverse corona can occur, thereby limiting precipitator performance.

REVERBERATORY FURNACE: A furnace with a shallow hearth; having a roof that deflects the flame and radiates heat toward the surface of the charge. Firing may be with coal, pulverized coal, oil, or gas.

RINGELMANN CHART: A standardized chart giving shades of gray by which the densities of columns of smoke rising from stacks may be compared.

ROAST: To heat to a point somewhat short of fusing, with access to air, so as to expel volatile matter or effect oxidation. In copper metallurgy, applied specifically to the final heating which causes self-reduction to occur by the reaction between the sulfide and the oxide.

ROASTER: 1. A contrivance for roasting, or a furnace for drying salt cake. 2. A reverberatory furnace or a muffle used in roasting ore.

ROASTING: 1. Heating an ore to effect some chemical change that will facilitate smelting. 2. The heating of solids, frequently to promote a reaction with a gaseous constituent in the furnace atmosphere.

ROASTING FURNACE: A furnace in which finely ground ores and concentrates are roasted to eliminate sulfur; heat is provided by the burning sulfur.

RUN OF MINE COAL: Unscreened bituminous coal as it comes from the mine.

S

SALAMANDER: A small portable incinerator, or a small portable heater burning coke or oil.

SCRUBBER: A device used to remove entrained liquids and solids from a gas stream by passing the gas through wetted "packing" or spray (see absorber).

SECONDARY AIR: Air introduced into a combustion chamber beyond the point of fuel and primary air introduction for the purpose of achieving more complete oxidation.

SECONDARY STANDARD: The national secondary ambient air quality which defines levels of air quality judged necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.

SINTERING: A heat treatment that causes adjacent particles of material to cohere or agglomerate at a temperature below that of complete melting.

SKIMMING PLANT: An oil refinery designed to remove and finish only the lighter constituents from the crude oil, such as gasoline and kerosene. In such a plant the portion of the crude remaining after the above products are removed is usually sold as fuel oil.

SKIP HOIST, INCLINED: A bucket or can operating up and down, receiving, elevating, and discharging bulk materials.

SLAG: The non-metallic top layer which separates from the metallic products in smelting of ores.

SLOP OR SLOP OIL: A term rather loosely used to denote odds and ends of oil produced at various places in a plant, which must be rerun or further processed in order to get in suitable condition for use. When good for nothing else, such oil usually goes into pressure-still charging stock, or to coke stills.

SMELT: In wood pulping, the molten chemicals from the kraft recovery furnace consisting mostly of sodium sulfide and sodium carbonate.

SMELTING: Any metallurgical operation in which metal is separated by fusion from impurities with which it may be chemically combined or physically mixed, such as in ores.

SMOKE: Small gas-borne particles resulting from incomplete combustion, consisting predominantly but not exclusively of carbon, ash, and other combustible material, and present in sufficient quantity to be observable.

SMOKE CANDLE(S): Apparatus used in collecting acid mists. Tubes or candles made from glass or plastic fibers are pressed into pads with thicknesses up to 2 inches and mounted in banks. Efficiency is much increased when the glass is treated with silicone oil to repel water, or when normally water-repellent plastic is used.

SMOKE UNIT: The number of "smoke units" is obtained by multiplying the smoke density in Ringelmann numbers by the time of occurrence in minutes. For the purpose of this calculation, a Ringelmann density reading is made at least once per minute during the period of observation. The sum of the Ringelmann density readings (made once per minute) during the period of observations would equal the number of smoke units.

SOILING: Visible damage to materials by deposition of air pollutants.

SOOT: Agglomerated particles consisting mainly of carbonaceous material.

SOUR: Gasolines, naphthas, and refined oils are said to be "sour" if they show a positive "doctor test"; i.e., if they contain hydrogen sulfide and/or mercaptans. Sourness is directly connected with odor, while a "sweet" gasoline has a good odor.

SOURCE: Any property, real or personal, or person contributing to air pollution.

SOURCE SAMPLE: A sample of the emission from an air contamination source, collected for analysis from within a stack.

SPARK ARRESTOR: A screenlike device to prevent sparks, embers, and other ignited materials larger than a given size from being expelled to the atmosphere.

SPEISS: Metallic arsenides and antimonides smelted from cobalt and lead ores.

SPRAY CHAMBER: The simplest type of scrubber consisting of a chamber in which spray nozzles are placed. They are used extensively as gas coolers because they have a low collection efficiency for anything but coarse particles.

STABILITY (STATIC STABILITY): The state of the atmosphere when it is stable relative to vertical displacements.

STACK OR CHIMNEY: Any flue, conduit, or duct arranged to conduct an effluent to the open air.

STACK SPRAY: A nozzle or series of nozzles installed in a stack above the breeching, used to inject wetting agents at high pressure to suppress the discharge of particulate matter from the stack.

STANDARD CONDITIONS: For source testing, 70°F (21.1°C) and 29.92" Hg (760mm Hg); for air quality measurements, 77°F (25°C) and 29.92" Hg (760mm Hg);

for chemistry, 273.1°K (0°C) and one atmosphere (760mm Hg); for petroleum refining, 60°F (15.55°C) and 14.7 psi (760mm Hg).

STATIONARY SOURCE: Any non-mobile building, structure, facility, or installation which emits or may emit any air pollutant.

STEAM DISTILLATION: Introduction of "open" steam into the liquid during distillation to assist in vaporizing the volatiles at a lower temperature.

STILL: A closed chamber, usually cylindrical, in which heat is applied to a substance to change it into vapor, with or without chemical decomposition. The substance, in its vapor form, is conducted to some cooling apparatus where it is condensed, liquefied, and collected in another part of the unit.

STOCK: In general, any oil which is to receive further treatment before going into finished products.

STOKER: A machine for feeding coal into a furnace, and supporting it there during the period of combustion. It may also perform other functions, such as supply air, control combustion, or distill volatile matter. Modern stokers may be classified as overfeed, underfeed, and conveyor. Any mechanical device that feeds fuel uniformly onto a grate or hearth within a furnace may be termed a "stoker."

STOPING: In mining, any process of excavating ore which has been made accessible by shafts and drifts.

STRAIGHT-RUN DISTILLATION: Continuous distillation which separates the products of petroleum in the order of their boiling points without cracking.

STRIPPER: Equipment in which the lightest fractions are removed from a mixture. In a natural-gasoline plant, gasoline fractions are stripped from rich oil. In the distillation of crude petroleum, light fractions are stripped from the various products.

SUBSTITUTION: A chemical reaction in which one or more atoms or groups of a molecule are replaced by equivalent atoms or groups to form at least two products, especially the replacement of hydrogen in an organic compound by another element or group.

SULFIDITY: An expression of the percentage makeup of chemical kraft cocking liquor obtained by the formula

$$\frac{Na_2S}{Na_2S + NaOH} \times 100$$

where the sodium compounds are expressed as Na_2O.

SUPERPHOSPHATE: Products obtained by mixing phosphate rock with either sulfuric or phosphoric acid, or both.

SURFACE CONDENSERS: A condenser in which the coolant does not contact the vapors or condensate. Most are of the tube and shell type. Water flows inside the tubes and vapors condense on the shell side.

SURGE TANK: A storage reservoir at the downstream end of a feeder pipe to absorb sudden rises of pressure and to furnish liquid quickly during a drop in pressure.

SWEETENING: The process by which petroleum products are improved in odor and color by oxidizing or removing the sulfur-containing and unsaturated compounds.

SYNERGISM: Cooperative action of discrete agents such that the total effect is greater than the sum of the two effects taken independently.

SYNTHETIC CRUDE: The total liquid, multi-component mixture resulting from a process involving molecular rearrangement of charge stock. Term commonly applied to the product from cracking, reforming, visbreaking, etc.

T

TAIL OIL: That portion of an oil which vaporizes near the end of the distillation; the heavy end.

TAIL GAS: The exhaust or waste gas from a process.

TALLOW: The rendered fat of animals that is white and almost tasteless when pure, composed of glycerides of fatty acids containing a large proportion of palmitic acid and stearic acid, and that is used chiefly in making soap, glycerol, margarine, candles, and lubricants.

TAPPING: Removing molten metal from a furnace.

TEMPERATURE INVERSION: An atmospheric layer in which temperature increases with altitude. The principal characteristic of a temperature inversion is its marked static stability, so that very little turbulent exchange can occur within it (see also inversion).

THEORETICAL AIR: The exact amount of air (stoichiometric air) required to supply the oxygen necessary for the complete combustion of a given quantity of a specific fuel or refuse.

THERMAL TURBULENCE: Air movement and mixing caused by temperature differences.

TOPPED CRUDE PETROLEUM: A residual product remaining after the removal, by distillation, of an appreciable quantity of the more volatile components of crude petroleum.

TOPPING: The distillation of crude oil to remove light fractions only.

TOTAL REDUCED SULFUR COMPOUNDS (TRS): Malodorous gases produced in the wood pulping industry exclusive of sulfur oxides. TRS usually includes hydrogen sulfide (H_2S), methyl mercaptan (CH_3SH), dimethyl sulfide (CH_3SCH_3), and dimethyl disulfide (CH_3SSCH_3). The concentration of TRS is usually expressed as H_2S regardless of the constituent compounds.

TURBULENCE: Atmospheric motions which produce a thorough horizontal and vertical mixing of the air.

TURNAROUND: The time between shutting down and starting up of process equipment for repair or maintenance.

TUYERES: Openings or nozzles in a metallurgical furnace through which air is blown as part of the extraction or refining process.

TWADDELL DEGREES (°TW): A measure of acid density and strength:

$$°TW = \frac{\text{sp. gr. } (60°/60°F)}{0.005}$$

Each twaddell degree corresponds to a specific gravity interval of 0.005.

U

ULTIMATE ANALYSIS (OF COAL): Contains the following, expressed in percent by weight:

Carbon	(C)	%
Hydrogen	(H_2)	%
Sulfur	(S)	%
Oxygen	(O_2)	%
Nitrogen	(N_2)	%
Moisture	(H_2O)	%
Ash	(H_2O)	%
		100.0%

UNDERFEED STOKER: A stoker consisting of a trough or pot-shaped report into which coal is forced by an endless screw or ram. Coal is fed to the fire zone by being pushed up from underneath.

UNIT OPERATION: 1. Methods by which raw materials may be altered into states, such as vapor, liquid, or solid without being changed into new substances with different properties and composition. 2. Recognition, study, application and control of the principles and factors utilized in a distinct and self-contained process (for example, filtration). This avoids the duplication of effort which attends the study of similar processes as though each process involved a unique set of principles.

UNIT PROCESS: 1. Reactions where raw materials undergo chemical change. 2. See unit operation (2).

UREA FORMS: A urea-formaldehyde reaction product that contains more than one molecule of urea per molecule of formaldehyde.

V

VACUUM JET (STEAM JET EJECTOR): A fluid nozzle that discharges a high velocity jet stream across a section chamber that is connected to the equipment to be evacuated. The gas in the chamber is entrained by the jet stream.

VAPOR: The gaseous phase of a substance that generally exists as a liquid or solid at room temperature.

VAPOR PLUME: The stack effluent consisting of flue gas made visible by condensed water droplets or mist.

VAPOR RECOVERY SYSTEM: System used in petroleum refining for separating a mixed charge of miscellaneous gases and gasolines into desired intermediates for further processing.

VENTURI SCRUBBER: A type of high energy scrubber in which the waste gases pass through a tapered restriction (venturi) and impact with low-pressure water. Gas velocities at the restriction are from 15,000 to 20,000 fpm and pressure drops from 10 to 70 inches water gage.

VISBREAKING: Viscosity breaking; lowering or "breaking" the viscosity of residual oil by cracking at relatively low temperatures.

VISIBILITY: In United States weather observing practice, the greatest distance in a given direction at which it is just possible to see and identify with the unaided eye (a) in the daytime, a prominent dark object against the sky at the horizon, and (b) at night, a known, preferably unfocused, moderately intense light source. After visibilities have been determined around the entire horizon circle, they are resolved into a single value of prevailing visibility for reporting purpose.

VISIBLE EMISSION: An emission of air pollutants greater than 5 percent opacity or 1/4 Ringelmann.

VOLATILE OR VOLATILE MATTER: 1. The gasoline constituents that can be driven off liquids and solids by the application of heat. 2. Specifically for coal, that portion which is driven off in gas or vapor form when coal is subjected to a standardized temperature test.

VOLATILE ORGANIC COMPOUNDS: Any compound containing carbon and hydrogen or containing carbon and hydrogen in combination with any other element which has a vapor pressure of 1.5 pounds per square inch absolute or greater under actual storage conditions.

W-X-Y-Z

WASTE HEAT BOILERS: Boilers which utilize the heat of exhaust gas or process gas to generate steam or to heat water.

WEAK WASH: In wood pulping, a liquid stream in the kraft process which results from washing of the lime mud.

WET COLLECTORS: Devices which use a variety of methods to wet the contaminant particles in order to remove them from the gas stream (see scrubbers).

WET FILTERS: A spray chamber with filter pads composed of glass fibers, knitted wire mesh, or other fibrous materials. The dust is collected on the filter pads.

WHITE LIQUOR: Cooking liquid used in the wood pulping industry. Kraft process: consists of approximately 1/3 sodium sulfide (Na_2S) and 2/3 sodium hydroxide (NaOH). Sulfite process: consists of sulfurous acid plus one of the following: calcium bisulfite, sodium bisulfite, magnesium bisulfite, or ammonium bisulfite.

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